A BIOMETRIC STUDY OF BASAL METABOLISM IN MAN

BY

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PREFACE.

In carrying out the work underlying this volume we have attempted to do more than to treat the available data for the basal metabolism of normal men, women and children by a method which is practically new in its application to human physiology; we have endeavored to make this investigation a prototype of that specialization in methods and coöperation in problems which we believe will be characteristic of the best scientific work of the future. We are convinced that this coöperation of specialists of widely dissimilar training is the only means by which science can attain both the height of refinement of measurement and analysis and the breadth of comparison and interpretation which is essential to continued progress.

The measurements considered in this volume have been made possible by the painstaking coöperation of a score or more fellow-workers, all of whom are connected or have been associated with the Nutrition Laboratory. How large their contribution has been will be evident from the names of the observers in the protocols of data and from the references to earlier publications scattered through the following pages. The exacting clerical and arithmetical work has been carried out at Cold Spring Harbor by the Misses Gavin, Holmes, Lockwood, and Peckham, who deserve the highest praise for the energy and care which they have devoted to this task. We are indebted to Major C. B. Davenport, Director, for permission to have this work carried out at the Station for Experimental Evolution. Finally it is a great pleasure to acknowledge our indebtedness to our associate, Professor W. R. Miles, who went over the first draft of the manuscript with us and offered many helpful suggestions, and to Mr. W. H. Leslie, in charge of the computing division at the Nutrition Laboratory, who has aided in correcting the proofs.

In taking up this work over two years ago, the authors fully recognized that the data must be wholly rearranged and interpreted as the statistical constants might indicate without any regard to opinions heretofore expressed from the Laboratory. Practically all of the conclusions already drawn at the Nutrition Laboratory have been fully substantiated by the statistical constants, and it is naturally a source of satisfaction that so little of the ground already held has had to be given up as a result of a wholly independent analysis from the outside.

This original conviction has been strictly adhered to, and every effort has been made to have the treatment physiologically sound throughout. We have endeavored to carry the analysis of the data to the practicable limits of the biometric formulas, at the same time preserving all that is of value in the older and simpler methods of treat-

ment which are more familiar to physiologists. We shall appreciate the fullest criticism by fellow physiologists, biologists, and statisticians, but criticisms to carry weight must be based on either statistical or physiological foundations and not merely the *ex cathedra* expression of the personal opinion that the new line of attack is valueless.

We are presenting this volume, not as a finished treatment of the subject of basal metabolism, but merely as an introduction to the many problems which await solution by the use of the more refined methods of analysis when more extensive data are available.

Nutrition Laboratory of the Carnegie Institution of Washington, Boston, July 10, 1918.

CHAPTER I.

INTRODUCTORY.

The purpose of this volume is to present the results of a first attempt to analyze the data of basal metabolism in normal men and women by the higher statistical or biometric formulas.

These methods, associated primarily with the names of Sir Francis Galton and Professor Karl Pearson, are steadily making their way in the most varied fields of biological work. While Pearson and his associates at the Biometric Laboratory and the Galton Laboratory for National Eugenics, University College, London, have touched on various problems of interest to physiologists in their studies of inheritance and of environmental influence, the methods have, up to the present time, been little employed in the domain of human physiology. Perhaps the most important papers in their bearing upon the problems with which we are here concerned are those by Bell,[1] by Whiting,[2] and by Williams, Bell and Pearson[3] on oral temperature in school children. Valuable as such studies unquestionably are from the standpoint of social and general biological science, statistical constants based on the returns of the public-school medical officer or of the prison surgeon can not be considered adequate for the requirements of modern nutritional physiology, in which measurements of a high degree of accuracy and made under carefully controlled conditions are indispensable.

Both the unfamiliarity of the biometric methods to most physiologists and the relative paucity of data on basal metabolism have probably been responsible for the failure of physiologists up to the present time to apply the higher statistical methods in this field. While physiologists have been engaged for several decades with the problem of the exact measurement of the metabolism of man and the lower animals, both by the direct determination of the amount of heat produced in the calorimeter and by the indirect calculation of heat-production from oxygen consumption and carbon-dioxide excretion, satisfactory data have until recently been exceedingly limited.

This state of affairs may be attributed to various causes. First of all, satisfactory apparatus is expensive and technical requirements exacting. The number of fully equipped laboratories and of adequately trained workers have, therefore, been very limited. Again, there is a personal element in all investigations based on normal human individ-

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[1] Bell, Biometrika, 1911, 8, p. 232.

[2] Whiting, Biometrika, 1915, 11, p. 8.

[3] Williams, Bell, and Pearson, Drapers' Company Res. Mem., Stud. Nat. Det., London, 1914, 9.

uals which is apt to be overlooked by those whose experimentation has been carried out on chickens, guinea pigs, or other animals or plants on the one hand or in the clinic on the other. In the study of normal metabolism the prejudices or suspicions of the subject must be overcome and his convenience considered. This imposes a limitation upon the number of measurements which can be fully realized by those only who have had to meet these difficulties. Finally, the progress of the work has shown the necessity for continuous refinement of method. Thus it is quite impossible to use for present purposes the observations of a few years ago. In the earlier work the necessity for complete muscular repose on the part of the subject under investigation was not fully enough realized. Individuals in the respiration chamber were allowed to move about, telephone, write, or otherwise occupy themselves. More recent work has indicated that such apparently trivial matters as the difference between the sitting and the reclining position or such slight exertion as that required to raise the hand from the side to the mouth may have a measurable influence on heat-production. Furthermore, it has long been known that the presence of food in the alimentary tract affects heat-production. The stimulatory action of food has, therefore, to be taken into account.

Thus the conditions under which the more truly basal metabolism of the individual may be measured have been continually narrowed. Of recent years students of human metabolism have reached a general understanding concerning the conditions under which the heat-production of an individual should be measured in order to obtain values of the metabolism constant which shall be comparable from individual to individual, and hence suitable as a standard basis of departure for all studies of the influence of special conditions, whether of sex, age, food, exercise or disease, upon the gaseous exchange. Determinations made on the individual during complete muscular repose and at a period 12 hours after the last meal, *i.e.*, in the post-absorptive condition, give what is commonly known as the basal metabolism. Until very recently the number of measurements which fulfil the modern high requirements was necessarily so small that it had not seemed worth while to apply the modern methods of analysis to them.

The development of series of measurements sufficiently large to justify the use of the more refined statistical formulas in their analysis has been in part due to a wider realization of the great practical as well as the purely theoretical importance of a detailed and precise knowledge of basal metabolism. The general public, as well as the handful of nutritional specialists, is being forced these days by conditions of unprecedented stress to a realization of the fact that an exact knowledge of human nutrition is not merely fundamental in the clinic and useful in home economics, but that it may even lie at the basis of national survival.

The desirability of applying the biometric formulas to the steadily increasing volume of data on basal metabolism in man has more than once suggested itself. Thus, as early as July 1915 Professor August Krogh, of Copenhagen, in his ever stimulating correspondence, urged that the data accumulated by the Nutrition Laboratory were already so extensive that the modern statistical formulas might profitably be employed in their expression and interpretation. After the manuscript for this volume was practically completed, a paper by Professor Armsby and his collaborators[4] appeared, giving the correlation between body-weight and daily heat-production and body-surface area and heat-production.

Fortunately the number of individuals whose basal metabolism has been determined is now fairly large. Dealing as we have in this volume with individuals measured at the Nutrition Laboratory, or by those who have been associated with the Laboratory, we are able to discuss the constants of nearly 250 adults and of about 100 infants. In the past these have been treated almost exclusively by the simple method of averages and graphic representation. But a series of metabolism constants, like other biological measurements, show differences among themselves. These differences must be due to either inaccuracies of measurement, or must represent real physiological differences between the individuals considered. That the latter rather than the former is true seems evident from the fact that technical errors in the making of the measurements have in all careful work been reduced to a minimum by the frequent use of physical tests of the apparatus, by the measurement of standard combustions, and by other precautionary measures which have placed the data of gaseous metabolism among the more accurately controlled of the physiological measurements. That the differences between the measurements of individuals are of the nature of real biological difference rather than of errors of observation is also clear from the fact that such attempts as have been made to obtain a more precise average metabolism constant by reducing the total heat-production to calories per kilogram of body-weight or to calories per square meter of body-surface have effected a material reduction in the amount of variation in the measures of the actually observed metabolism of individuals. Notwithstanding this correction for the physical characteristics of the individual due to the reduction of the gross heat-production to calories per kilogram or calories per square meter of body-surface, the variation in the metabolism constant is not entirely eliminated. It seems necessary, therefore, in any thoroughgoing investigation of metabolism in man, to take account of the variation from individual to individual, as well as of the general average. Furthermore, the fact that some lessening in the differences in the metabolism

[4] Armsby, Fries, and Braman, Proc. Nat. Acad. Sci., 1918, **4**, p. 1. See also Journ. Agric. Research, 1918, **13**, p. 43.

constants of a series of individuals is made by reducing them to units of body-weight or body-surface indicates that the total metabolism of the individual is correlated with his physical characteristics. Thus the desirability of a detailed investigation of the correlation of the various physical and physiological measurements which have been made suggests itself.

Such investigations of variation and correlation can be carried out only by means of the biometric formulas. A full justification for the application of the higher statistical methods to the data of basal metabolism is to be found in the fact that these methods have been successfully applied in other fields in which the observational data exhibit comparable irregularity. During the past two decades instances of the demonstration of law and order in processes hitherto apparently chaotic have been rapidly multiplying, while on the other hand, long-maintained biological theories have been shown to be groundless by the mathematical description and analysis of series of measurements. This fact establishes a strong presumption that the same condition will be found to apply in the field of human metabolism. The presumption has seemed to justify at least a preliminary test of the methods.

It seems desirable to outline at the start the possibilities of the statistical formulas in their application to the problems of basal metabolism.

First of all, these formulas permit a more concise and adequate *descriptive statement* of the results of experimentation. The statistical method furnishes not merely an average measure of metabolism, but also a measure in a single constant of the deviation of the individual determinations of metabolism from their average value. The average value of the metabolism constant serves many useful purposes, but it is no more truly a characteristic of the series of measurements which have been made than their differences among themselves. Measures of variability in metabolism are, therefore, quite as necessary for a full understanding of the physiological problem as are measures of the average values. Such constants have been determined during the course of this work, and expressed in both absolute and relative terms. The measures in absolute terms are particularly useful for some purposes, while those in relative terms permit direct comparison of the variability of metabolism constants with those of other physical and physiological measurements in man.

Again, one of the greatest possibilities of the statistical method lies in the determination of the degree of association or correlation of different physical and physiological or of different physiological characters. For example, we know that in general the total heat-production of a tall individual is greater than that of a short individual, that the heat-production of a heavy individual is greater than that of a light individual, and so on. But what is needed for a full and scientific analysis of

the whole problem is *some measure of the intensity* of these and many other interrelationships, *expressed on such a scale that comparisons between various characters may be easily and directly made.* This end is readily attained by the use of the modern correlation formulas.

The analysis may be pushed further. We have just said that tall individuals produce on the average a larger number of calories than short ones, and that heavy individuals set free on the average more heat than light ones; but tall individuals are on the average heavier than short ones, and the question naturally arises whether their greater heat-production may not be due exclusively to their greater average weight. This problem can be solved only by correcting the correlation between stature and heat-production for the influence of the correlation of both stature and total heat-production with body-weight. A quite similar method of analysis may be applied when it is desired to correct the relationship between two variables, for example between age and heat-production, for the influence of both of two other variables, say stature and body-weight.

Knowing the correlation between two variables (for example, body-weight and total heat-production) it is possible within certain limits of accuracy to predict the average value of one from the known magnitude of the other. Thus it is possible to pass at once from measures of interdependence on the universal scale of correlation to coefficients showing just how much on the average an associated character increases in units of the actual scale on which it is measured for each unit's change in the first variable. These relationships are of the greatest practical importance, in that they enable us to determine the most probable metabolism of an unknown subject of given stature, weight, and age, and these predicted values may serve as a control in cases in which it is desired to investigate the influence of particular conditions, *e.g.* the incidence of a specific disease, on metabolism.

Finally, one of the great advantages of the use of the statistical method lies in the system of probable errors which are provided by the biometric constants. Metabolism varies from individual to individual. If the average value of a series of determinations be employed as a basis of argument concerning some physiological relationship, the worker must fully recognize the fact that a repetition of the measurements upon another set of individuals apparently comparable with the first would give averages somewhat different. The probable errors of random sampling, to be discussed in somewhat greater detail in a special section on methods of statistical analysis, do much to establish the limits of trustworthiness of not only the arithmetical means or averages but of all the other statistical constants. Thus the biometric formulas make possible a far more definite conception of the limits of trustworthiness of metabolism constants than has heretofore been possible.

Turning now from generalities to concrete problems, we may outline very briefly the actual physiological problems upon which we have touched.

First of all it may be stated that this volume contains the raw data for age, body-weight, stature, pulse-rate, and gaseous exchange, with the computed heat-production, in 47 men and 35 women hitherto unpublished. These are laid before the reader, together with the data for 89 male and 68 female adults and the 51 male and 43 female infants already published from the Nutrition Laboratory. These represent a contribution to the problem of human metabolism of experimentally determined facts which must be taken into account even by those who may be unwilling to accept the results of the statistical analysis to which all the data at our disposal have been subjected.

Turning to the results of statistical analysis, properly so called, we note the following:

1. The more important statistical constants of the largest available series of metabolism measurements have been determined. These must serve as standards in metabolism work until more extensive data are available.

2. The relationship between physical and physiological measurements of the human individual has been discussed in as great detail as possible by means of correlation constants. Specifically, we have considered the relationship between both body-weight and stature, representing physical measurements, and the physiological measurements, pulse-rate, gaseous exchange, and total heat-production, and determination has been made of the effect upon these correlations of correction for other factors.

3. The degree of interdependence between various physiological characters has also been considered. Specifically, the relationships between pulse-rate and gaseous exchange, and between pulse-rate and total heat-production and heat-production per unit of body-weight and of body-surface have been determined.

The illustrations presented in the following pages should amply demonstrate the material advances in our knowledge of physiological processes which may be expected when the degree of interrelationship between various physical characters and physiological activities, or between physiological activities themselves, shall be generally measured on a definite quantitative scale.

4. The validity of the so-called body-surface law has been tested by means of criteria hitherto unapplied. This "law" has been discussed as an empirical means of predicting the metabolism of an unknown subject and as an expression of a true physiological interrelationship.

5. In connection with the investigation of the so-called body-surface law, various methods of predicting the total heat-production of an unknown subject from sex, age, stature, and body-weight have

been considered in detail. Standard tables have been prepared from which the most probable metabolism of a subject, whose normal metabolism is unknown, may be predicted as a basis of comparison with that measured in a pathological state. Such tables should be of great value in the clinical investigations which should contribute much to the future advancement of medical science.

6. By the use of such tables, the metabolism of subjects of particular characteristics, or subjected to special conditions, has been reconsidered. Specifically, the problems of the typical or atypical character of certain series of metabolism measurements, of the differentiation of the sexes with respect to metabolic activity, of the metabolism of athletes as compared with non-athletic individuals, of vegetarians as compared with non-vegetarians, and of individuals suffering from disease have been investigated.

In preparing this report on the results of the application of the biometric formulas to the data of basal metabolism in normal men and women we have utilized only the measurements made at the Nutrition Laboratory or by those who have been associated with it. This limitation has been made, not because there are not many satisfactory determinations which have been made in other laboratories, but because, all things considered, it has seemed most satisfactory to avoid invidious comparisons by the discrimination which would have been necessary had we gone outside the series of determinations for which responsibility rests directly or indirectly upon the Nutrition Laboratory.

Finally, a few words concerning the form in which the results of this investigation are presented: It has not seemed desirable to transform a research publication into a primer of statistics, or to state results which are necessarily mathematical in a popular and non-mathematical form. We have, however, made every effort to express our results in a form so clear and direct that they will be fully comprehensible to those without special statistical training. In the case of all the more complicated processes we have given the formulas by which the results were reached. This has been done to enable those who may care to do so to check through our work from the beginning. The reader who is interested in end results rather than in methods should pass over these features, just as the general biologist must pass over the details of method and the section on structural formulas in a paper by an organic chemist, realizing that they are essential to the technical development of the subject. The analogy is by no means wide of the mark. The statistical technique is of course complicated, as are the manifold technical refinements necessary in the experimental phases of the measurement of metabolism in man. An adequate presentation of the subject demands a statement of the formulas employed quite as much as a description of the physical and chemical apparatus used in the laboratory phases of the work. With this feature of the following

treatment the non-statistical reader must bear as patiently as possible. There is no royal road to statistical analysis, and the popularization of statistical methods is quite comparable with the problem of the popularization of organic or physical chemistry. The demand for simplification can, so far as those of us who have been working in this field can now see, be attained only at a serious loss of effectiveness.

To assist the non-statistical reader as much as possible in the understanding of our results we have added a summary at the end of each chapter in which we have given the results in a form as general and non-statistical as possible. With these precautions, and with the coöperation of those who may attempt to follow us through these pages, we trust that a highly difficult subject has been presented without important loss in the technical detail which is essential to those who may care to pursue the subject further and in a manner comprehensible to the general physiologist.

CHAPTER II.

METHODS OF STATISTICAL ANALYSIS.

Before taking up the actual data with which we have to deal, a brief discussion of the statistical formulas employed will be necessary although it is not possible to give an adequate introduction to the use of the statistical methods. These methods are complicated and many pitfalls abound in the field of statistical reasoning. This section may, however, give the reader definitions of terms and a general conception of the method of attack.

The first statistical constant to be determined for a series of measurements is the arithmetic mean or average value. This is simply the sum of all the observations divided by their number. It is already familiar to the physiologist and need not be discussed further.

The second statistical constant with which we shall have to deal in the treatment of these data is a measure of the deviation of the individual measurements from their average value. Physiologists in common with psychologists and other investigators have sometimes measured the variation in their observations by obtaining and averaging the differences between the individual readings and the general average. Thus an *average deviation*, or an *average dispersal*, of the individual measurements about the general average for the whole series of individuals dealt with, is obtained. This *average deviation* is very useful for some purposes, but for more refined work has three disadvantages. (1) Some of the measurements are smaller while others are larger than the general average for the whole series of individuals dealt with. Thus some deviations are positive while others are negative in sign. In obtaining an average value which shall furnish a true measure of scatter both above and below the mean, it is necessary to disregard the signs and thus to do violence to one of the laws of mathematical usage. (2) The significance to be attached to a deviation is considered proportional to its actual magnitude. It may be legitimate to regard a large deviation as both absolutely and relatively more important than a small one. (3) The average deviation is poorly suited for use in more complicated statistical work.

The larger deviations can be given a proportionately greater weight by squaring all the deviations, summing these squares, and dividing by the number of deviations to obtain the mean-square deviation. The square root of this mean-square deviation is the measure of variation, scatter, or dispersal most used by the statistician. It is called the *standard deviation*, S. D. or σ. There are great practical advantages in the use of the standard deviation, in that it is particularly suited

for the more complicated calculations involved in the determination of measures of interrelationship.

The standard deviation may be calculated by actually obtaining the deviations of the individual measurements from the general average, squaring these deviations, dividing by the number of observations, and extracting the square root of the quotient. Thus if x represents the value of an individual measurement, $\bar{x}$ the average of all the N measurements

$$\sigma_x = \sqrt{\Sigma[(x-\bar{x})^2]/N}$$

where σ_x is to be read "the standard deviation of the measurement x" and Σ denotes the summation of all the squared deviations. Thus in the case of a series of 16 athletes given in our table of data on p. 40 the total weight is 1181.1 kilograms and the average weight 1181.1/16 = 73.8 kilograms. The sum of all the daily heat-productions is 30,025 calories and the average daily heat-production 1876.6, or in round numbers 1877 calories. The deviation of the individual weights, w, from the average weight, $\bar{w}$, and of the individual heat-productions, h, from the average heat-production, $\bar{h}$, are given in table 1.

TABLE 1.—*Deviations and squares of deviations of body-weight, w, and heat-production, h, from their respective averages.*

Subject.	w	$(w-\bar{w})$	$(w-\bar{w})^2$	h	$(h-\bar{h})$	$(h-\bar{h})^2$
W. A. S.	56.3	−17.5	306.25	1562	−315	99225
C. J. D.	56.7	−17.1	292.41	1524	−353	124609
M. Y. B.	63.5	−10.3	106.09	1677	−200	40000
R. D. S.	63.5	−10.3	106.09	1619	−258	66564
H. R. W.	73.9	+ 0.1	0.01	1842	− 35	1225
P. D. F.	71.2	− 2.6	6.76	1810	− 67	4489
C. D. R.	74.0	+ 0.2	0.04	1908	+ 31	961
M. A. M.	66.0	− 7.8	60.84	1695	−182	33124
W. F. M.	62.4	−11.4	129.96	1816	− 61	3721
H. W.	108.9	+35.1	1232.01	2559	+682	465124
J. H. R.	82.2	+ 8.4	70.56	1978	+101	10201
D. H. W.	82.1	+ 8.3	68.89	2034	+157	24649
E. G.	78.9	+ 5.1	26.01	2126	+249	62001
M. H. K.	79.0	+ 5.2	27.04	1944	+ 67	4489
W. S.	88.5	+14.7	216.09	2017	+140	19600
F. G. R.	74.0	+ 0.2	0.04	1914	+ 37	1369

The standard deviations are therefore given by

$$\Sigma[(w-\bar{w})^2] = 2649.09, \qquad \Sigma[(h-\bar{h})^2] = 961351$$
$$\Sigma[(w-\bar{w})^2]/N = 165.5681 = \sigma_w^2 \qquad \sigma_w = 12.867$$
$$\Sigma[(h-\bar{h})^2]/N = 60084.44 = \sigma_h^2 \qquad \sigma_h = 245.12$$

The standard deviation furnishes a measure of variation in terms of the unit in which the variable was measured, *i.e.*, in number of heart-beats, in number of respirations per minute, or in number of calories produced per 24 hours. If comparison between the variability of characteristics measured in different working units is to be made, it is necessary to reduce the two standard deviations to a comparable

basis by expressing them as percentages of their respective means. Thus, if x represents heat produced per 24 hours and y represents pulse-rate, it is quite impossible to say from a comparison of σ_x and σ_y whether pulse-rate or heat-production is the more variable character. But if the two standard deviations be expressed as percentages of their respective means,

$$V_x = \frac{100\sigma_x}{\bar{x}} \qquad V_y = \frac{100\sigma_y}{\bar{y}}$$

it is possible to determine which of the two characters is *relatively* more variable.

Thus in the case of the measurements of body-weight and total heat-production given above, the relative variabilities are:

$$V_w = \frac{100\sigma_w}{\bar{w}} \qquad V_h = \frac{100\sigma_h}{\bar{h}}$$

or numerically

$$V_w = \frac{12.867 \times 100}{73.8} = 17.43 \qquad V_h = \frac{245.12 \times 100}{1876.6} = 13.06$$

This relative variation constant is known as the *coefficient of variation.* It shows in the present case that the body-weight of the athletes is about 4.4 per cent more variable than their daily heat-production.

We now turn to the problem of the measurement of interdependence or correlation.

Remembering that we are seeking a measure of the degree of interrelationship of the magnitudes of two variables, it is first necessary to adopt a standard with which individual measures of body-weight, body-surface, metabolism, pulse-rate, or other variables may be compared in order to determine their place in their own series. Such a standard is furnished by the average value of the character in the series of individuals available. This arithmetical mean has the advantage for metabolism work that it has been regularly used as a standard value by various workers. The only difference between our use of the mean and that of some other writers on metabolism is that the average value which we employ as a standard is always the average for the particular series of individuals under consideration, not an average for some selected standard series. Thus, in working with athletes, vegetarians, or all normal men the averages employed as standards are those for athletes, vegetarians, or for all normal men, as the case may be.

Let x be the measure of any physical or physiological characteristic of an individual, y the measure of any other physical or physiological characteristic—for example, oxygen consumption, carbon-dioxide output, or calories of heat-production, in the same individual. Then if we designate by bars the average values of these two characteristics in the series of individuals dealt with, $(x-\bar{x})$, $(y-\bar{y})$ furnish at once the

measure of the position of an individual in the whole series of measurements. Values with the negative sign indicate a position below the average, values with a positive sign a position above the average of the series as a whole, while the numerical value gives at once the magnitude of the deviation.

Now remembering that $(x-\bar{x})$ and $(y-\bar{y})$ are values with signs, it is clear that if we take the products of these deviations we shall have positive products for all values with like signs and negative products for the values of all deviations with unlike signs. Summing these products with regard to sign for the whole series of individuals under investigation, the net total will be positive if the two measures x and y tend to vary in the same direction, that is, if y tends to be above its mean value in individuals in which x is above its mean value and y tends to lie below its mean value in individuals in which x lies below its mean value.

For example, the table for the athletes given above shows the actual amount of the deviation of the weight and the daily heat-production of each individual above or below the mean weight and mean heat-production of the whole group of athletes. The fact that two positive or two negative signs tend to occur together shows at a glance that there is some correlation between body-weight and total heat-production. The products of these deviations are given in table 2.

TABLE 2.—*Products of deviations of body-weight and daily heat-production from their respective means.*

Subject.	$(w-\bar{w})$	$(h-\bar{h})$	$(w-\bar{w})\ (h-\bar{h})$
W. A. S.	−17.5	−315	+ 5512.5
C. J. D.	−17.1	−353	+ 6036.3
M. Y. B.	−10.3	−200	+ 2060.0
R. D. S.	−10.3	−258	+ 2657.4
H. R. W.	+ 0.1	− 35	− 3.5
P. D. F.	− 2.6	− 67	+ 174.2
C. D. R.	+ 0.2	+ 31	+ 6.2
M. A. M.	− 7.8	−182	+ 1419.6
W. F. M.	−11.4	− 61	+ 695.4
H. W.	+35.1	+682	+23938.2
J. H. R.	+ 8.4	+101	+ 848.4
D. H. W.	+ 8.3	+157	+ 1303.1
E. G.	+ 5.1	+249	+ 1269.9
M. H. K.	+ 5.2	+ 67	+ 348.4
W. S.	+14.7	+140	+ 2058.0
F. G. R.	+ 0.2	+ 37	+ 7.4
Sum (Σ)	± 0.0	±0.0	+48331.5

In 15 of the 16 cases the heat-production is larger than the average heat-production when weight is larger than the average weight and smaller than the average heat-production when weight is smaller than the average. Summing the products with regard to sign, we have

$$+48335.0-3.5=+48331.5,$$

which divided by $16=3020.7188$.

Thus the sum of the products of the deviations of x and y from their respective means for the whole series of individuals, divided by the number of individuals considered, furnishes a mean product-deviation which is a measure in absolute terms of the closeness of interdependence of the two characters under investigation.

To obtain a measure in relative terms (that is in a form to facilitate comparison between unlike characters) some standard of the amount of the deviation from the general means in the case of the two characters is essential. The mean product-deviation must be expressed as a fraction of the product of the deviations of the two characters in the whole series of individuals from their respective means—that is, of $\sigma_x \sigma_y$.

The measure of interdependence in relative terms is therefore merely the ratio of the mean product-deviation discussed above to the product of the two standard deviations in the whole series. Thus

$$r_{xy} = \frac{\Sigma[(x-\bar{x})\ (y-\bar{y})]\ /N}{\sigma_x\ \sigma_y}$$

is the measure of interdependence sought.

For the illustration in hand, the athletes, we have numerically,

$$r_{wh} = \frac{3020.7188}{12.867 \times 245.12} = \frac{3020.7188}{3153.9590} = 0.958$$

This is the familiar product-moment coefficient of correlation of the statistician.

The coefficient of correlation measures the closeness of interdependence between two variables on a universally comparable scale, the range of which is unity. Thus a coefficient of 0 represents an absence of all interdependence [5] between the two variables. A correlation coefficient of 1 indicates perfect interdependence. Thus if there be no correlation between x and y, the measurement of the x character furnishes no information whatever concerning the magnitude of the y character in the same individual. If, on the other hand, there be perfect correlation—a practically unknown quantity in biological work—the magnitude of the y character is known as soon as the x character has been measured.

Empirically, the correlation coefficient is generally found to be positive in sign, but it may be either positive or negative. When y becomes larger as x increases in magnitude the correlation is positive in sign. When y decreases as x increases, correlation is negative in sign. The correlation formula is so written that the sign is automatically given in the process of determining the constant.

[5] There are conditions under which this is not true, but for the purposes of this volume the statement is practically valid.

In metabolism work positive correlations are numerous. For example, the correlation between body-weight and total heat-production in the 136 men available for this investigation is +0.796, or about 80 per cent of perfect interdependence. Physiologists have, of course, known of the existence of this relationship. The statistical method has not been necessary to demonstrate its existence. What the statistical formula has done is to *measure on a quantitative scale* a relationship concerning which ideas were heretofore vague and qualitative only. The positive sign shows that total heat-production increases with body-weight.

Age is the only character for which correlations have in this work been found to be consistently negative in sign. The correlation between age and total heat-production in these 136 men has been found to be −0.306. This shows that heat-production *decreases* as age *increases* and measures, on the universally comparable scale of unity, the closeness of the interrelationship between these two variables.

For purposes of comparison a measure of the interrelationship of two variables on a universal scale is invaluable. Fortunately it is possible, by proper statistical formulas, to pass from measures in terms of correlation to measures of interdependence expressing in the concrete units of actual measurement the average change in the y character associated with a unit variation in the x character, or *vice versa*.

The formulas are

$$(y-\bar{y}) = r_{xy}\frac{\sigma_y}{\sigma_x}(x-\bar{x}) \qquad (x-\bar{x}) = r_{xy}\frac{\sigma_x}{\sigma_y}(y-\bar{y})$$

or in a somewhat different form

$$y = \left(\bar{y} - r_{xy}\frac{\sigma_y}{\sigma_x}\bar{x}\right) + r_{xy}\frac{\sigma_y}{\sigma_x}x \qquad x = \left(\bar{x} - r_{xy}\frac{\sigma_x}{\sigma_y}\bar{y}\right) + r_{xy}\frac{\sigma_x}{\sigma_y}y$$

All the symbols in these equations are familiar to the reader from the immediately foregoing paragraphs.

In statistical terminology such equations are called *regression equations*. This term, which has an historical significance, is now well established in the literature and we shall use it, or sometimes a perhaps better term *prediction equation*, throughout this volume. In equations like the first of the two above we speak of the regression of y on x, which is equivalent to saying the prediction of y from x. In the case of the second equation we speak of the regression of x on y, or of the prediction of x from y.

Such equations are easily reduced to numerical form by the substitution of the statistical constants. For example, the correlation between body-weight and total heat-production in a group of athletes has been shown above to be expressed by a coefficient of $r_{wh} = 0.958$.

Expressing this relationship in terms of regression, we have (remembering that $\sigma_w = 12.867$ and $\sigma_h = 245.12$).

$$(h-\bar{h}) = r_{wh}\frac{\sigma_h}{\sigma_w}(w-\bar{w}) = 0.958\frac{245.12}{12.867}(w-\bar{w})$$

or

$$(h-\bar{h}) = 18.250\,(w-\bar{w})$$

In a form somewhat more convenient for practical work, *i.e.*, in that of the characteristic equation, the relationship is

$$h = \left(\bar{h} - r_{wh}\frac{\sigma_h}{\sigma_w}\bar{w}\right) + r_{wh}\frac{\sigma_h}{\sigma_w}w$$

Noting that numerically $\bar{w} = 73.8$ kilograms and $\bar{h} = 1876.6$ calories, we have

$$h = \left(1876.6 - 0.958\frac{245.12}{12.867}73.8\right) + 0.958\frac{245.12}{12.867}w$$

which gives

$$h = 529.7 + 18.3\,w$$

Such equations predict the average value of the y character associated with a given grade of the x character, or the average value of the x character associated with a given value of the y character. For examples, the values of h predicted by the equation are the average values of a series of individuals of given stature, body-weight, or any other physical or physiological character used as a basis of prediction. They represent the *most probable* heat-production of an individual determination providing that the distribution of variation in heat-production is symmetrical about its mean and the relationship between the character from which prediction is made and heat-production be capable of expression by a linear equation.

In the following pages the straight lines due to such equations are frequently represented on a diagram showing by the position of a dot the value of both the x and the y character of all the individuals.

Such scatter diagrams bring out clearly the fact that the predicted measure is an average and can be taken to represent only the most probable value of the individual case. It is necessary, therefore, to consider the amount of deviation which may be expected to occur about the predicted mean.

The standard deviation of the predicted character, say h, for the individuals of any group is

$${}_x\sigma_h = \sigma_h\sqrt{1 - r_{xh}^2}$$

where x denotes stature, body-weight, age or any other character with respect to which the individuals may be classified in the investigation of metabolism.

The practical physiological significance of this statistically well-known relationship seems to be rather great.

First of all, if r_{xh} be small the error of prediction of the heat-production, h, of a single individual from the value of x will necessarily be large. This is not due to any inadequacy of the statistical formulas, but is the inevitable consequence of great physiological variability.

On the other hand, if there be a group of n individuals of a specified grade of x, say x_p, the prediction of the average heat-production of the individuals of this group can be carried out with far greater accuracy. Thus the standard deviation of the predicted mean value $\bar{h}_{x_p}$ is

$$\frac{\sigma_h\sqrt{1-r_{xh}^2}}{\sqrt{n}}$$

while the probable error is

$$\frac{0.67449\ \sigma_h\sqrt{1-r_{xh}^2}}{\sqrt{n}}$$

where $\bar{h}_{x_p}$ is the mean heat-production of individuals of a specific grade, p, of character x, for example body-weight, body-surface, pulse-rate, or any other character.

Thus it is clear that when a physical character of an individual is known—for example, stature or body-weight—the values of metabolism predicted from it will show certain deviations from the actual values of the individual subjects, but the statistician can even predict with fair accuracy what the amount of this deviation will be. The failure to attain exact prediction merely illustrates the fact that physiology, like biology in general, is not as yet a science in which certainty as to the individual instance is attainable. Chapter VI will be devoted almost entirely to the problem of the closeness of prediction of heat-production from physical characters.

As an illustration of the importance of the preceding formulas we may note that the probable error of the mean predicted heat-production of 4 typhoid patients would be $1/\sqrt{4}$ or one-half as large as the probable error of a single individual, while the probable error of the mean predicted heat-production of 9 subjects would be $1/\sqrt{9}$, or one-third as large as the probable error of one observation.

To determine how closely the predicted values agree with the empirical average for the group of individuals classified with respect to any character, x, we have merely to compare the mean values actually observed with those due to the regression equation by means of a graph. Such diagrams, of which a number occur in the following pages, permit one to judge by the eye the goodness of fit of the regression equations. In some cases special mathematical tests of the closeness of agreement of the empirical and theoretical means are given, but an explanation of the nature of these tests is unnecessary here.

In some cases we have found it necessary to use regression equations in which the value of one variable, z, is predicted from those of two others, x and y, or from that of three others, w, x and y. Formulas for these will be given when used.

Throughout the following pages we shall have frequent occasion to use *partial correlation formulas.* Total heat-production is correlated with stature and with body-weight; but stature and body-weight are also correlated, taller individuals being on the average heavier than shorter ones. The problem now arises: May not the correlation between stature and total heat-production be merely the resultant of the correlation between body-weight and heat-production on the one hand and body-weight and stature on the other? To solve this problem we have to correct the correlation between stature and total heat-production for the influence of body-weight. Or, in statistical terminology, we must determine the partial correlation between stature, s, and heat-production, h, for constant body-weight, w. This is done by the use of the formula

$$_{w}r_{sh} = \frac{r_{sh} - r_{ws}\, r_{wh}}{\sqrt{1-r_{ws}^2}\,\sqrt{1-r_{wh}^2}}$$

Here $_{w}r_{sh}$ is to be read "the correlation between stature and heat for constant body-weight." The technical expression "for constant body-weight" means merely "with the influence of body-weight eliminated." If the correlation between stature and total heat-production were merely the resultant of the correlation between weight and heat-production and weight and stature, $_{w}r_{sh}$ should be sensibly zero. For example, for the 136 men, using the constants as given on pages 59 and 96, we have:

$$r_{sh} = +0.6149$$

$$r_{ws} = +0.5725 \qquad 1-r_{ws}^2 = 0.6722 \qquad \sqrt{1-r_{ws}^2} = 0.8199$$

$$r_{wh} = +0.7960 \qquad 1-r_{wh}^2 = 0.3663 \qquad \sqrt{1-r_{wh}^2} = 0.6052$$

$$_{w}r_{sh} = \frac{0.6149 - 0.5725 \times 0.7960}{0.8199 \times 0.6052} = \frac{0.1592}{0.4962} = 0.321$$

$$1 - {_{w}r_{sh}^2} = 0.8969 \qquad E_{_{w}r_{sh}} = 0.6745\frac{1-{_{w}r_{sh}^2}}{\sqrt{N}} = 0.0519$$

Thus the partial correlation between stature and heat-production for constant body-weight is only about half the magnitude of the uncorrected value. It is clear, therefore, that the greater heat-production of tall individuals is due largely to their greater weight. The fact that the partial correlation has a material and statistically significant positive value indicates that the observed relationship between stature and metabolism is not merely the resultant of the correlations between stature and weight and between weight and metabolism.

In certain instances we have found it desirable to determine the relationship between two variables for constant values of two other variables. Thus ${}_{aw}r_{sh}$ is to be read "the correlation between stature, s, and heat-production, h, for constant age, a, and body-weight, w."

The actual formulas used in computing the partial correlation coefficients are given in each instance.

The partial-correlation method has been of great service in this study and will, we believe, prove to be a powerful analytical tool in the investigation of physiological relationships in many fields.

We now turn to the subject of the probable errors of the statistical constants.

Because of the differences which obtain between the individual determinations of a series of metabolism measurements, the statistical constants of such measurements will generally differ to some extent from series to series. For example, the average heat-production per square meter of body-surface per 24 hours of 72 men selected by Gephart and DuBois from a Nutrition Laboratory publication is 926.65 calories, whereas the average heat-production of 64 other men examined by the Nutrition Laboratory is 924.14 calories. Thus the two series differ in heat-production per square meter of body-surface by 2.51 calories. The standard deviations of heat-production per square meter of the two series are 62.59 and 71.92 calories, or show a difference of 9.33 calories. When another series of measurements is available it will probably give averages and variabilities which differ slightly from either of these. That this should be so is simply a matter of common experience.

The statistician as such can do nothing whatever to eliminate the individuality of the subjects to which these differences are primarily due or to minimize the slight experimental errors of measurements upon which they to some extent depend. He can, however, furnish criteria of the trustworthiness of statistical constants based on series of observations of known variability and number. These criteria are the so-called *probable errors*, or more precisely *probable errors of random sampling*. Such probable errors are entirely statistical in nature and have nothing whatever to do with the *possible errors* of measurement. They assume the technical or biological correctness of the observations and measure merely the degree of trustworthiness of statistical constants based on series of observations.

In the calculation of the probable error two factors must obviously be taken into account. The first is the variability, the second is the number of the measurements dealt with. If a character, either physical or physiological, is extremely variable it is obvious that an average based upon a given number of determinations will be less trustworthy than one based upon a character which is very slightly variable. For example, the addition of one very heavy individual to a series will

make an enormously greater difference in the average weight of the series than it will in the average pulse-rate, for body-weight is a far more variable character than pulse-rate. The trustworthiness of a constant based on a series of measurements is inversely proportional to the variability of the individual measurements. On the other hand it is reasonable to assume that the precision of a statistical constant increases as the number of observations upon which it is based becomes larger. Thus the average metabolism of 100 individuals is admittedly more desirable as a basis for physiological generalization than an average based on 10 individuals; yet the trustworthiness of the constants is not directly proportional to the number of observations upon which they are based, but stands in the ratio of the square roots of these numbers. Thus the probable error of an average based on 10,000 individuals would not be $100/10000 = 1/100$ of that based on 100 individuals, but only $\sqrt{100}/\sqrt{10000} = 1/10$. The practical consequence of this relationship is that while precision increases with the number of the observations, the increase in precision is not directly proportional to the labor involved in the making of the measurements. After a degree of precision which meets the practical requirements is attained, further work may be regarded as lying beyond the limit of diminishing returns. Of course the need of greater refinement may at any time arise and demand the accumulation of a number of data which for earlier work would have been considered superfluous.

Details concerning the calculation of the probable errors—a term having an historical significance and not as appropriate as might be found—which can be obtained from text books on statistical methods, need not detain us here. A few words are in order concerning the interpretation of the probable error, the value appended with a plus and minus sign to the various statistical constants. It is in reality a measure of the variability of that constant which would be found if it could be determined an infinitely large number of times upon random samples of the same number of measurements and drawn from the same population as that upon which the constant is based. It is a measure of this variability of the statistical constant about its mean so chosen that half of the values would lie inside and half of them outside the limits of the probable error. Thus if the mean value of a character in an infinitely large population were 86 and the probable error for samples of 100 were ± 5, 86 ± 5 would indicate that if a large series of samples of 100 individuals each were drawn at random from this population half of these would show averages ranging from 81 to 91 while the remaining 50 per cent would lie below 81 and above 91.

The distribution of these means based on random samples of 100 individuals each would be an orderly one. Thus in the comparison of two means it is possible for the statistician to estimate the chances for (or against) their being based on identical material. Or, conversely,

it is possible to estimate from the observed differences in the constants the chances of the materials being differentiated. This is, of course, the practical application of the principle. The physiologist desires to know, for example, whether an observed difference between two constants, one based on athletic and the other on non-athletic individuals, indicates a real biological or physiological difference attributable to athletic training, or whether it is merely of the order to be expected as the result of random drawing of groups of subjects of the number dealt with.

For example, the daily heat-production of 16 athletes is found from table 16 to be 1876.56 ± 41.33 calories. That of the first supplementary series of 28 men is 1605.18 ± 28.19 calories. The difference between these two constants is 271.38 ± 50.03 calories. The difference is 5.42 times as large as its probable error and the odds against its being due to errors of random sampling are large.[6] Thus we may conclude that athletes are different from ordinary individuals in their gaseous metabolism.

Again we note that in a series of 72 men selected by Gephart and Du Bois from the Nutrition Laboratory publications the average heat-production is 1623.46 ± 14.11, whereas in another series of 64 individuals it is 1641.05 ± 19.48. The difference is 17.59 ± 24.05. Thus the difference is less than its probable error and can not be considered statistically significant. In short the two groups of men may be considered to show the same average metabolism.

The practical use of the probable error is almost invariably in the carrying out of comparisons. The investigator desires to know whether a particular statistical constant differs either from some preconceived or theoretical standard or from some other constant. For example, the physiologist may wish to know whether the mean metabolism of women differs significantly from that of men. In the case of correlation an apparently, but not essentially, different problem presents itself. One often desires to know whether there be any relationship at all between two variables. He then inquires whether an empirically found value of the correlation coefficient has a "significant" value. This is necessary because of the fact that if correlations were based upon small series of individuals drawn at random from an infinitely large series in which the correlations were zero, a *numerical value* would in many instances be obtained. This is true for the same reason that a small number of determinations of basal metabolism on a group of febrile patients would show an average value differing from that obtained on a small group of normal subjects, whether there be any real influence of fever on metabolism or not.

In such cases we wish to know whether the correlation differs

[6] Throughout this volume we have taken differences of 2.5 or 3 times as large as their probable errors to be significant, always remembering that the interpretation of probable errors is difficult when the number of observations is small.

significantly from zero, which would be found if an infinitely large series of observations were available. For example, in table 18 we show that the correlation between stature and pulse-rate in 121 men is $+0.0916 \pm 0.0608$, while for 90 women it is -0.0669 ± 0.0708. These constants differ from zero by 1.51 and 0.94 times their probable errors and consequently would not be considered to prove the existence of a real positive correlation between stature and pulse-rate in the case of *men as a class* or of a real negative correlation in the case of *women as a class*. In short, the probable error indicates that the series of determinations available is too small to justify any generalization concerning the numerical magnitude of the correlation between stature and minimum or basal pulse-rate other than that it is exceedingly small if it exists at all. A comparison of the coefficients obtained in the subsamples shown in table 18 justifies this view, for in the several series available for adult males the coefficients are sometimes positive and sometimes negative in sign.

If we turn from the relationship between stature and pulse-rate to that between stature and total heat-production given in table 32, Chapter IV, we note that the correlation for the total males is $+0.6149 \pm 0.0360$, while for the total females it is $+0.2318 \pm 0.0629$. The first of these two constants is 17.1 while the second is 3.7 times as large as its probable error. Thus there can be no question whatever concerning the statistical significance of the deviation of these correlation coefficients from the zero which would be the average value if there were no correlation between stature and total heat-production. We may conclude, therefore, that as far as the relationship between stature and total heat-production is concerned the series of determinations available furnish a fair basis for generalization concerning the numerical relationship between stature and total heat-production in men and women at large.

This discussion of the probable error has been of the most general nature, but it may be sufficient to dispel the confusion which seems to exist in the minds of some between technical errors of measurement and the probable errors of random sampling of statistical constants, and to enable the reader unaccustomed to statistical reasoning to follow arguments based on probable errors in the following pages.

Finally a few words concerning the actual routine of calculation are in order. The formulas for the determination of r used in explaining this coefficient above are not the most useful for practical work. In the calculation of the standard deviation it is quite unnecessary to obtain the actual deviation in each case. If the deviations are not wanted for other purposes the standard deviation is easily obtained from[7]

$$\sigma_x = \sqrt{\Sigma(x^2)/N - [\Sigma(x)/N]^2} = \sqrt{\Sigma(x^2)/N - \bar{x}^2}$$

[7] Harris, Am. Nat., 1910, **44**, p. 693.

where $\Sigma(x)$ and $\Sigma(x^2)$ denote the sums of the individual measurements and their squares.

Furthermore we may write

$$r_{xy} = \frac{\Sigma(xy)/N - \bar{x}\bar{y}}{\sigma_x \sigma_y}$$

where $\Sigma(xy)$ denotes the sum of the product of the two measures under consideration, the bars denote their means, and the sigmas their standard deviations.

This method is particularly suited for physiological work. The worker has merely to sum the products of the two measures under consideration for all the individuals dealt with, divide by the number of individuals, subtract the product of the means of the two variables from this mean product, and divide the remainder by the product of the two sigmas. The standard deviations are easily obtained by summing the squares of the actual measurements, dividing by the number of individuals, subtracting the square of the mean of the character, and determining the square root of the remainder.

TABLE 3.—*Calculation of moments of body-weight and daily heat-production.*

Subjects.	Body-weight in kilos.	Body-weight squared.	Total heat-production.	Heat-production squared.	Product, weight times total heat.
W. A. S.	56.3	3169.69	1562	2439844	87940.6
C. J. D.	56.7	3214.89	1524	2322576	86410.8
M. Y. B.	63.5	4032.25	1677	2812329	106489.5
R. D. S.	63.5	4032.25	1619	2621161	102806.5
H. R. W.	73.9	5461.21	1842	3392964	136123.8
P. D. F.	71.2	5069.44	1810	3276100	128872.0
C. D. R.	74.0	5476.00	1908	3640464	141192.0
M. A. M.	66.0	4356.00	1695	2873025	111870.0
W. F. M.	62.4	3893.76	1816	3297856	113318.4
H. W.	108.9	11859.21	2559	6548481	278675.1
J. H. R.	82.2	6756.84	1978	3912484	162591.6
D. H. W.	82.1	6740.41	2034	4137156	166991.4
E. G.	78.9	6225.21	2126	4519876	167741.4
M. H. K.	79.0	6241.00	1944	3779136	153576.0
W. S.	88.5	7832.25	2017	4068289	178504.5
F. G. R.	74.0	5476.00	1914	3663396	141636.0
Sum (Σ)	1181.1	89836.41	30025	57305137	2264739.6

This method gives constants with the maximum degree of exactness. It has the special advantage for physiological work that, after the fundamental summations have been made for a first series of experiments, subsequent determinations may be added and the correlation on the basis of a larger N determined merely by the addition of the summations of first and second powers and products for the new series. Or, if one suspects that a single aberrant individual, or group of individuals, has too much weight in determining a given coefficient, the

first and second powers and the products for the specific individual, or the sum of these values for the group of individuals, may be subtracted from the original value of $\Sigma(x)$, $\Sigma(x^2)$, $\Sigma(y)$, $\Sigma(y^2)$ and $\Sigma(xy)$ and the means, standard deviations, and correlation be redetermined on the basis of the reduced N.

This has been the method followed in the calculations of the present study. We have used the original measurements as published in the fundamental tables, pp. 38-47, without modification or grouping. This has necessitated rather heavy arithmetical work, since the squares and products have been very large. The course has, however, the merit of introducing no error not already inherent in the data.

As an illustration of method we again take the constants for body-weight and daily heat-production in our smallest series, the 16 athletes. The values required are given in table 3. These give

$$\Sigma(w) = 1181.1 \qquad \Sigma(w^2) = 89836.41 \qquad N = 16$$

$$\Sigma(w)/N = \bar{w} = 73.8188 \qquad \sigma_w = \sqrt{\Sigma(w^2)/N - \bar{w}^2} = 12.8670$$

$$\Sigma(h) = 30025 \qquad \Sigma(h^2) = 57305137$$

$$\bar{h} = 1876.5625 \qquad \sigma_h = 245.1209$$

$$\Sigma(wh) = 2264739.6 \qquad \Sigma(wh)/N = 141546.225$$

and finally

$$r_{wh} = \frac{141546.225 - (73.8188 \times 1876.5625)}{12.8670 \times 245.1209} = 0.9577$$

$$1 - r^2 = 0.0828 \qquad E_r = 0.0140$$

That in presenting our results we have retained more figures than are really significant for physiological work is quite as clear to ourselves as to anyone who may desire to lop off the constants. But we have borne continually in mind the fact that these constants may in many instances be required for further calculation. It has seemed desirable, therefore, to retain a number of places sufficiently large to enable those who care to do so to check particular phases of our work without going back to the raw data.

CHAPTER III.

INDIVIDUALS AND MEASUREMENTS CONSIDERED.

In the first of the three sections into which this chapter is divided we list up and briefly discuss the measurements (both physical and physiological) considered in these pages.

In the second section we catalogue the series of individuals with the results of the measurements which have been made upon them. These are the data upon which our constants are based.

In the third section we apply certain criteria adapted to determining the suitability for the purposes of the present study of the individuals upon whom measurements have been made.

I. MEASUREMENTS CONSIDERED.

The following are the measurements which have been considered. The symbol in parenthesis is the one used to designate the measurement in the statistical formulas. A brief explanation of the method employed in making the determination is given later.

Stature (s), or height, in centimeters.
Body-weight (w), in kilograms.
Body-surface, or area, in square meters, as estimated by Lissauer formula (a_L).
Body-surface, in square meters, as estimated by Meeh formula (a_M).
Body-surface, in square meters, as estimated by Du Bois height-weight chart (a_D).
Pulse-rate (p), in beats per minute.
Carbon-dioxide output (c). Total in cubic centimeters per minute.
Oxygen consumption (o). Total in cubic centimeters per minute.
Carbon-dioxide production, in cubic centimeters per minute, per kilogram of body-weight (c_k).
Oxygen consumption, in cubic centimeters per minute, per kilogram of body-weight (o_k).
Body-temperature (t).
Heat-production (h). Total heat-production (indirect calorimetry) per 24 hours in calories.
Heat-production per 24 hours per kilogram of body-weight (h_k).
Heat-production per 24 hours per square meter of body-surface according to Lissauer formula (h_L).
Heat-production per 24 hours per square meter of body-surface estimated by Meeh formula (h_M).
Heat-production per 24 hours per square meter of body-surface estimated by Du Bois height-weight chart (h_D).

The following are the details which seem essential to an understanding of the measurements utilized.

Stature.—Stature, without shoes, was measured in adults by means of a graduated vertical rod with an adjustable horizontal bar which was lowered to the top of the head.

In infants the length must be taken as comparable with the stature of the adult. In discussing the data for infants we shall, therefore, refer to the relationship between *stature* and other characters rather than to that between *length* and other characteristics. This is done to maintain uniformity in the statistical symbols.

In measuring infants the vertical rod was of course replaced by a fixed and a movable vertical on a horizontal scale.

Body-weight.—Body-weight, in kilograms, was always taken without clothing. While weight of clothing may be a negligible factor in life-insurance examinations, or even in anthropometric investigations, it can not be disregarded in careful physiological work. Experience at the Nutrition Laboratory has shown that weight of clothing will amount to about 4.0 kilograms for men and 2.5 kilograms for women.

Body-surface.—In conformity with the custom of physiologists, heat-production has for certain purposes been expressed in calories per square meter of body-surface per 24 hours.

The measurement of body-surface presents very great difficulties. If the superficial area of our subjects had been measured directly a series of determinations one-tenth as large as that here considered could probably not have been secured. The whole question of body-surface in relation to heat-production will be discussed in detail in Chapter VI. For the moment it is necessary to note merely that for infants surface was estimated by the Lissauer[1] formula

$$a=10.3\sqrt[3]{w^2}$$

where a=area in square centimeters and w-weight in kilograms. When the original Nutrition Laboratory series was published [2] the Meeh formula [3]

$$a=12.312\sqrt[3]{w^2}$$

for adults was generally accepted. The results of later studies have also been expressed by this formula and in addition estimated by the Du Bois height-weight chart,[4] which is based on the linear body-surface formula of D. and E. F. Du Bois.[5]

This covers sufficiently the physical measurements.

The body temperature of our own subjects has not been considered. In discussing the literature we have, sometimes, referred to temperature, designated in our formulas by t. In such cases the reader must consult the paper cited for details as to measurement.

The physiological determinations can best be explained by a single general description of the apparatus and method of experimentation.

[1] Lissauer, Jahrb. f. Kinderheilk, 1902, N. F., **58**, p. 392.
[2] Benedict, Emmes, Roth, and Smith. Journ. Biol. Chem., 1914, **18**, p. 139.
[3] Meeh, Zeitschr. f. Biol., 1879,, **15**, p. 425.
[4] Du Bois and Du Bois, Arch. Intern. Med., 1916, **17**, p. 863.
[5] Du Bois and Du Bois, Arch. Intern. Med., 1915, **15**, p. 868.

Before proceeding to technical details a few words on the general principles involved may be useful to the reader who approaches this subject for the first time.

The calorie is the unit of measurement of energy transformation. *Theoretically* the measurement of heat-production by the calorimeter is the only correct method of measuring the amount of the katabolism. *Practically* the technical difficulties of the actual measurement of the quantity of heat produced by a living organism are so great that for many purposes direct may be replaced by indirect calorimetry—that is, by the calculation of heat-production from the amount of the respiratory exchange and the ratio of the volume of carbon dioxide exhaled to the volume of oxygen absorbed.

The application of this method depends upon the fact that the heat set free in the combustion of a given substance may be determined with precision in the laboratory. Thus to make possible the calculation of the total heat-production from the measurements of the two gases in the respiration chamber, or when possible from measures of the two gases and of nitrogen excretion, it is necessary to ascertain only the calorific values of unit volumes of oxygen and carbon dioxide for the combustion of the substances which are oxidized in the human body.

The consideration of the CO_2/O_2 ratio, or the *respiratory quotient* as it is commonly designated, as well as the actual volumes of the two gases, is necessary because of the fact that the calorific value of either of these gases is determined by the nature of the substances oxidized. Thus a liter of CO_2 derived from the combustion of carbohydrates (starch) corresponds to 5.043 calories,[6] a liter of CO_2 derived from fat corresponds to 6.680 calories, and a liter of CO_2 derived from protein has an equivalent of 5.690 calories. The calorific equivalents for a liter of oxygen are 5.043 calories for carbohydrates, 4.755 calories for fat, and 4.600 calories for protein.

Thus the ratio of the carbon dioxide set free to the oxygen used in the combustion of carbohydrates, fats, and protein is, within limits, constant and specific. For the combustion of all carbohydrates, the CO_2/O_2 ratio must be unity. Since the composition of the several fats and proteins varies, the CO_2/O_2 ratio must also vary slightly.

There are other difficulties to be considered in the indirect determination of heat-production. The synthesis of fats from carbohydrates greatly disturbs the CO_2/O_2 ratio.

The use of indirect calorimetry for work in man has, however, been fully justified by the experimentation of Atwater and his associates [7] and shown to be applicable to short periods by Gephart and Du Bois.[8]

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[6] Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, **174**, p. 858; average values obtained from table 1.

[7] Atwater and Benedict, U. S. Dept. Agr., Office Expt. Sta., 1899, Bul. **69**; 1902, Bul. **109**; 1903, Bul. **136**. Benedict and Milner, U. S. Dept. Agr., Office Expt. Sta., 1907, Bul. **175**.

[8] Gephart and Du Bois, Arch. Intern. Med., 1915, **15**, p. 850 and p. 854.

At the present time it is generally admitted by students of metabolism that for the short observation periods, which are essential for the measurement of the individual in a state of complete muscular repose and in the post-absorptive condition, the errors of computation of heat-production by the indirect method are actually less than those of direct measurement in the calorimeter.[9]

We have expressed total heat-production in calories per 24 hours. This has seemed to us the most desirable unit for a universal standard. In employing this unit of time there has been no attempt to obscure the fact that the actual measurements covered shorter periods. In practically all cases, however, the 24-hour constant is based upon a number of periods.

Since in indirect calorimetry the thing actually measured is the gaseous exchange, we have worked out and discussed the chief statistical constants for the measures of gas volume as well as for the total heat-production indirectly derived from them. Anyone who may be inclined to discredit the results as expressed in calories computed by the formulas of indirect calorimetry may see our chief conclusions established by the constants based on the directly measured gaseous exchange.

In passing, it is worth while to note that the high degree of consistency in our oxygen and carbon-dioxide measurements affords strong evidence for the trustworthiness of our constants.

The coefficients of correlations between oxygen consumption and carbon-dioxide excretion in the adults[10] are given in table 4.

TABLE 4.—*Correlation between two measures of gaseous exchange.*

Series.	N	Correlation between CO_2 and O_2, r_{co}	$\frac{r_{co}}{E_{r_{co}}}$
Men.			
Original series:			
Athletes	15	0.9799 ± 0.0069	142.0
Others	62	0.8962 ± 0.0169	53.0
Whole series	88	0.9488 ± 0.0072	131.8
Gephart and Du Bois selection	71	0.9350 ± 0.0101	92.6
First supplementary series	28	0.9507 ± 0.0123	77.3
Original and first supplementary series	116	0.9432 ± 0.0069	136.7
Second supplementary series	19	0.8738 ± 0.0366	23.9
Other than Gephart and Du Bois selection	64	0.9333 ± 0.0109	85.6
All men of three series	135	0.9335 ± 0.0075	124.5
Women.			
Original series	66	0.8794 ± 0.0188	46.8
Supplementary series	35	0.9662 ± 0.0076	127.1
Both series	101	0.8917 ± 0.0137	65.1

[9] A review of the problem of direct and indirect calorimetry is given by Krogh, The Respiratory Exchange of Animals and Man. Longmans, Green and Co., London, 1916, p. 9.

[10] Because of the technique in the measurement of oxygen consumption and carbon-dioxide production necessarily adopted in the case of infants, we have not been able to include the correlations for these series.

All of the constants are of a very high order indeed. In the original published series $r = 0.949 \pm 0.007$, while in the Gephart and Du Bois selection $r = 0.935 \pm 0.010$. The first two series of men ($N = 116$) gives $r = 0.943 \pm 0.007$, while the whole series ($N = 135$) gives $r = 0.934 \pm 0.008$. The first and second series of women differ a little more in the correlations. In the first $r = 0.879 \pm 0.019$, whereas in the second the result is $r = 0.966 \pm 0.008$, a difference of 0.087 ± 0.021.

The high correlations justify great confidence in the technical phases of the work. Had there been large errors in the measurement of either oxygen consumption or carbon-dioxide production, correlations of the order here tabled could hardly have been secured.

The basal metabolism of all our subjects was measured by well-known methods.

A few determinations were made by the Tissot method[11] with all of the niceties of manipulation that have been worked out by Dr. T. M. Carpenter, of the Nutrition Laboratory staff.[12] The larger number of measurements in the original Nutrition Laboratory series were made with a universal respiration apparatus devised at the Nutrition Laboratory and designated as the unit apparatus. The earlier and more modern forms of this apparatus[13] differ somewhat in the provision made for expansion in the closed air-circuit. Certain of the results obtained with the bed calorimeter[14] are quite comparable with those due to the use of the universal respiration apparatus and are included in the original Nutrition Laboratory series.

Finally, a number were made with the clinical respiration apparatus at the New England Deaconess Hospital, under the skillful technique of Miss M. A. Corson, of the Laboratory staff.[15]

An elaborate series of comparisons, in which all of these various methods have been critically tested, shows that the basal metabolism determined by any one is comparable with that determined by any other.[16]

The heat-productions determined directly in the bed calorimeter are omitted, and are replaced by those indirectly computed from the gaseous exchange and the respiratory quotient. Thus all the values of total heat-production are due to indirect calorimetry and are exactly comparable among themselves.

All of the apparatus employed at the Nutrition Laboratory was made and tested there. That used at Battle Creek was built on the ground, but was subsequently tested and approved by Roth and one

[11] Tissot, Journ. de physiol. et de pathol. gén., 1904, **6**, p. 688.

[12] Carpenter, Carnegie Inst. Wash. Pub. No. **216**, 1915, p. 61.

[13] For the original description see Benedict, Am. Journ. Physiol., 1909, **24**, p. 345. The more modern form is described in Deutsch. Archiv. f. klin. Med., 1912, **107**, p. 156.

[14] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. **123**, 1910, p. 45.

[15] The description of this apparatus is given in detail by Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, **174**, pp. 857, 898, 939.

[16] Carpenter, Carnegie Inst. Wash. Pub. No. **216**, 1915.

of us. All of the operators acquired their technique personally in the Nutrition Laboratory. The data are, therefore, due not merely to uniform method and apparatus but to comparable manipulation throughout.

The routine involved the appearance of the subjects at the Laboratory at about 8 a. m., in the post-absorptive condition, *i.e.*, about 12 hours after taking their last food. They then lay down upon a couch or bed and remained perfectly quiet, usually half an hour prior to the first period. Absence of muscular activity during the experimental periods was assured by the bed being provided with a graphic registering device which indicated the slightest alteration in the change of position of the center of gravity of the body, or by the attachment of a chest or thigh pneumograph which registered slight muscular movement.

Experiments were usually made in several periods of 15 minutes, with interims of 15 to 20 minutes. To secure the most representative value possible, experiments were usually made two, and frequently many more, days with the same subject.

The pulse was nearly always taken, and usually the oral temperature. Subjects with febrile temperature were rejected.

In selecting the periods of observation to be used, those in which there was an absence of muscular activity were chosen. This was assured by having the individual under observation lie on a bed, one side of which rested on a knife edge while the other was supported by a spiral spring. A change in the level of the bed altered the tension of a pneumograph connected with a tambour and kymograph. The smallest motion of any kind, even a movement so slight as to be imperceptible to the observant trained nurse, disturbed the linearity of the kymograph record. Thus periods of perfect muscular repose could be selected on the basis of an instrumental record alone, without the possibility of the personal equation of the observer playing any part.

In the respiration calorimeter, in which each experiment lasted at least 1½ hours, such complete muscular repose could not be obtained as in the shorter periods with the universal respiration apparatus. But here the subjects fully understood the necessity for quiet, and while the kymograph records naturally show somewhat greater irregularity in the long than in the selected short periods, the subjects were remarkably quiet and the irregularities in the tracings are so slight as to indicate negligible muscular activity.

The computation of heat-production is usually based upon the oxygen consumption, making allowances for the slight changes in the calorific equivalent of oxygen with varying respiratory quotients. The calorific value of oxygen is much more nearly constant, irrespective of the character of the katabolism, than is that of carbon dioxide, and hence in practically all of the cases we have used the oxygen consumption. In a few instances where the oxygen determinations were faulty,

we have used the carbon-dioxide production. When either the oxygen or the carbon-dioxide determination was missing, we have assumed, when no better evidence is available, a common respiratory quotient of 0.85. In certain cases we have used quotients determined on the day antecedent to or the day subsequent to the period on which a constant is based. Usually the quotient of 0.85 is used.

As in these short experiments it was frequently difficult to secure accurate collection of urine, we have not attempted to compute the calories from protein nor the non-protein respiratory quotient, but have taken the calorific equivalent of oxygen as used by Zuntz and Schumburg,[17] making no special correction for the influence of the protein metabolism upon the respiratory quotient and the calorific equivalent of carbon dioxide and oxygen. In short experiments, particularly with uncertainty as to the nitrogen excretion in the urine, this procedure is recommended by Loewy[18] as giving results practically within 1 per cent of the true value.

2. DATA ANALYZED.

The data analyzed in this volume were gathered in the course of the various investigations which have been carried out at the Nutrition Laboratory, or by those collaborating with this Laboratory, during the past several years. Two series have been published. The data are given in full in this publication and are therefore available to anyone who cares to go over the analytical phases of the present treatment.

The materials are the following:

A. A series of 51 male and 43 female infants investigated by Benedict and Talbot.[19] This series was chosen rather than the first series published by Benedict and Talbot[20] because, in the opinion of these workers, the second series represents a far more homogeneous series of materials. This will be designated as the *infant series*.

B. A series of measurements on 89 men and 68 women made at various times at the Nutrition Laboratory and elsewhere by coöperating investigators, and published[21] as a basis for a comparison of basal metabolism in men and women, athletic and non-athletic individuals, vegetarians and non-vegetarians, and so forth. This will be designated as the *original adult series* to distinguish it from two supplementary series of measurements of adults hitherto unpublished.

C. Determinations of basal metabolism in 28 men and 1 woman carried out subsequently to the series described immediately above. These data will be designated as the *First Supplementary Series*. (The woman has been included with the second supplementary series.)

D. *The Second Supplementary Series*. This comprises 19 men and 34 women.

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[17] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.
[18] Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4**, (1), p. 281.
[19] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. **233**, 1915.
[20] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. **201**, 1914.
[21] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139.

These four series are the sources of the constants published in this volume. From the figures given in the protocols in which these data are brought together (pages 38 to 47) the reader who desires to do so may verify the calculation of any of our constants. The exact statement of the several measurements of each individual subject will not have its primary value in the possibility of the verification of the arithmetic of the present work, but in enabling the physiologist to criticize freely our fundamental observations or groupings of observations.

These series form units of data upon which constants have been based. It may seem to the reader that physiologically more satisfactory results might be secured by sorting the entire number of individuals in these several series into more homogeneous groups as determined by some special structural or physiological character, for example, according to age, stature, body-weight, body-surface, or pulse-rate. For the sake of argument, at least, this must be admitted. Such divisions will be made in the latter part of this volume. With regard to the question of division of materials the following considerations must be borne in mind.

In segregating the data for purposes of analysis, two factors must be taken into account. The more finely the materials are sub-divided the more uniform will the groups of observations be, provided, of course, that the divisions are logically made. On the other hand, the smaller the groups are made the larger will be the probable errors of random sampling attaching to the final constants, for these probable errors are inversely proportional to the square roots of the numbers of observations upon which they are based.

The method of dividing the materials has been determined by both physiological considerations and by the practical exigencies of the work.

When the application of biometric formulas to the problem of basal metabolism in man was taken up, the only series of data available were the original series of adults and the infant series. These were classified according to sex in both series.

The women of the *original adult series* have not been further subdivided for purposes of general calculation. The men, however, are both more numerous than the women and apparently more heterogeneous in physiological characteristics. A number are athletes and a number are vegetarians.

After the work which has been done on the metabolism of athletes[22] it would seem unjustifiable to merely lump together athletes, non-athletes, vegetarians and non-vegetarians and all other individuals of the same sex without determining what results are to be secured when they are treated independently. We have, therefore, segregated a

[22] Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 243. See also page 244 of this volume.

group of 16 athletes and computed all the constants upon which we have based our arguments for the individuals of this group alone. The smallness of the number of individuals available necessarily results in relatively high probable errors. The same course was also followed for the male vegetarians, but the number of these was so small that many purely statistical difficulties arose, and since the metabolism of vegetarians has not been shown to differ significantly from that of men at large,[23] we have omitted the discussion of this group.

After the segregation of these two groups, the athletes and the vegetarians, there remain 62 other individuals, which have been used as the basis of another series of correlations. These are designated as the "men of the original series other than athletes and vegetarians," or for convenience merely as the "other men."

The constants are also computed for the whole series of 89 men of the original series.

When the first supplementary series became available it was treated as a whole in the case of men and also combined with the total men of the first series.

The same course was followed when, before the completion of the long routine involved in the calculations, the second supplementary series fortunately came to hand.

To avoid all possible objections which might arise from the fact that the individuals included were selected and the groups limited by one or the other of the authors of this report, we have felt it desirable to work out the constants on the basis of materials grouped for purposes quite different from the present ones by some other investigator.

Most fortunately this has been done by such experienced workers as Gephart and Du Bois[24] who have combined their own 7 metabolism determinations for men with 72 of the 89 published by Benedict, Emmes, Roth, and Smith, for the purpose of obtaining an average metabolism constant.

From the 89 men of our original adult series, Gephart and Du Bois have seen fit to discard 17. While we shall discuss the validity of their reasons for this course, we are heartily glad to have at our disposal, for comparison with the groupings of subjects arranged or limited by ourselves, those which have been approved by others whose training and personal experience in the clinic justifies them in passing judgment upon such matters. The elimination has been made by Gephart and Du Bois in the following manner:

"All those over 50 years of age were arbitrarily excluded and also those under 20 years of age."

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[23] Benedict and Roth, Journ. Biol. Chem., 1915, **20**, p. 231. See also page 245 of this volume.
[24] Gephart and Du Bois, Arch. Intern. Med., 1915, **15**, p. 858.

By this ruling the following individuals,[25] 10 in all, were withdrawn from the series:

(87) F. P.	(73) L. D. A.
(81) V. G.	(77) W. W. C.
(22) E. J. W.	(67) F. M. M.
(31) H. F.	(3) M. H. K.
(79) C. H. H.	(7) H. W.

"In order to rule out those who were distinctly over or under weight, the subjects were all plotted in a curve, the height forming the abscissæ and the weight the ordinates. All but 9 of the subjects could be grouped between two lines not very far apart. Of the 9, W. S., O. F. M., Prof. C., H. F., F. E. M., and F. A. R. were evidently much heavier in proportion to their height.

"Two of the 9, R. A. C.[26] and B. N. C., were evidently very light in proportion to their height. E. P. C. came just outside the line, but so close that he has not been excluded from the averages."

This gives "a fairly homogeneous total" of 79 individuals "where average metabolism was 34.7 calories per square meter per hour, or exactly the same as that of the original 89 before the addition of 7 and the exclusion of 17."

Note that (31) H. F. is excluded on the basis of both age and ratio of weight to height.

Thus the individuals omitted from the Nutrition Laboratory series are 17 in number as follows:

(2) W. S.	(75) R. A. C. (or R. I. C.?)	(73) L. D. A.
(28) O. F. M.	(25) B. N. C.	(77) W. W. C.
(30) Prof. C.	(87) F. P.	(67) F. M. M.
(31) H. F.	(81) V. G.	(3) M. H. K.
(17) F. E. M.	(22) E. J. W.	(7) H. W.
(36) F. A. R.	(79) C. H. H.	

This series we have designated as the Gephart and Du Bois selection.

Thus Gephart and Du Bois have settled for us the question of the specific men of the original 89 studied at the Nutrition Laboratory to be included in the determination of a set of statistical constants; but difficulties arose when the first and second supplementary series of men became available for analysis and we attempted to apply the same criteria to them in order to obtain a larger number of subjects chosen according to approved clinical standards.

The elimination of individuals on the basis of age presented no obstacle. Of course the distinction between a man of 20 and another of 19 is a purely arbitrary one, but such arbitrary distinctions have to be made, and in selecting according to standards established by others one merely has to follow the rules which have been laid down.

For the elimination of subjects on the basis of height and weight the case is quite different. Here too the division is necessarily an arbitrary one, but Gephart and Du Bois have given no definite criteria by

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[25] The numbers in parentheses and the initials refer to the fundamental table of data on pages 38 to 47.

[26] Evidently a misprint for R. I. C. of Benedict, Emmes, Roth, and Smith.

which the individuals who are to be discarded may be distinguished from those who are to be retained in the series. They have said merely that "all but 9 of the subjects could be grouped between two lines not very far apart."

Had not the authors designated by initials the men to be excluded in this specific series of determinations it would have been impossible for another writer to decide, without actual statistical criteria, which should be thrown out. It is, therefore, quite out of the question to divide any other series in a comparable manner without determining (*a*) what shall be the slope of the lines which cut off the outlying members of a series on the basis of height and weight, and (*b*) what the amount of separation of these lines shall be, *i.e.*, what body-weights may be allowed in any group of individuals of the same height, or *vice versa*.

The selection of a criterion by which individuals are to be discarded from a series[27] is so important a matter (if those in presumably good health are to be discarded from control series on the basis of physical configuration at all) that it seems worth while to go into the matter in some detail. The individuals to be segregated are distributed in a scatter diagram or a "correlation surface," according to the measure of heights and weights. From this surface it is desired to cut off certain areas, representing individuals of aberrant ratios of weight to height.

Any line of division should take into account the general averages for both stature and body-weight. We shall, therefore, select as a standard a line which will pass through the intersection of these two means. This establishes one position of the line. The slope must be ascertained. This is determined by the correlation between the two variables. Thus the equation required is given by

$$(w-\bar{w}) = r_{sw}\frac{\sigma_w}{\sigma_s}(s-\bar{s})$$

or, taking the constants for the original 89 men from tables in this and the following chapter, $\bar{s}=172.449$, $\sigma_s=7.8032$, $\bar{w}=64.334$, $\sigma_w=10.7302$, $r_{sw}=0.5320$, and we have numerically,

$$w = -61.818+0.732\,s$$

This is the axis of the swarm of observations represented by the line $A-A$ in diagram 1.

In this diagram we have drawn the lines, $D-D$, cutting off the individuals discarded by Gephart and Du Bois as exactly as we have been able to do from their description of their method, but in a manner to give them the benefit of every doubt concerning the position and slope of the lines. These lines do not run parallel to the best-fitting axis, $A-A$, of the swarm of measurements distributed with regard to

[27] Obviously if subjects are to be ruled out of the class of "normals" available for use as control subjects in comparison with pathological cases, it would be better to have them discarded on the basis of logical criteria *before* rather than *after* the expenditure of time and labor necessary to the determination of their basal metabolism.

both weight and stature. We must, therefore, conclude that the criteria for the discarding of the individuals omitted can not be regarded as well chosen.

Thus, while we have retained the selection made by Gephart and Du Bois, we have done so merely because we have desired to work in one instance with a series of individuals chosen by other workers, not because we personally feel that there is any advantage in discarding the individuals removed by them.

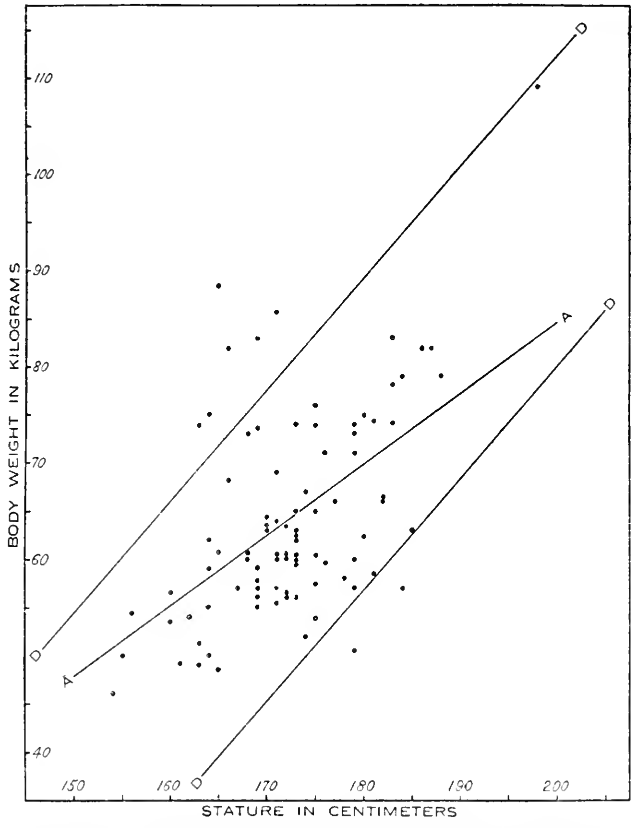

Diagram 1.—Distribution of stature and weight in original series of men. Individuals outside of the lines D–D were excluded by Gephart and Du Bois on the ground of aberrant proportions. Logically the lines cutting off aberrant individuals, D–D, should parallel the axis of the swarm of observations, A–A.

The course followed seems to us to obviate practically every source of criticism. If statistical constants be calculated from the smaller groups of observations, there can be no objection to combining these into larger groups in order to ascertain how their constants compare with those based upon the original segregations. If, however, the constants be determined from the massed materials only, there is always the justification for criticism based on the lumping of quite

unlike data. The determination of constants on the basis of groups of individuals just as they became available has the advantage that the selection of groups can not be influenced by the personal equation of the statistician.

Later in this volume we shall make some further classification of the data.

Since the data have been treated in individual groups as collected, in special groups arranged by both ourselves and others, and in combined series, there can be no criticism whatever as to selection of data. The constants for the data arranged in a number of different ways have been presented and discussed in as nearly as possible an unbiased manner. The full original data are laid on the table for anyone who cares to arrange them differently, to go back of our constants, or to carry the analysis farther than we have done.

The fundamental measurements upon which all the statistical constants in this volume are based appear in tables A to D.

Tables A and B for male and female infants require no comment. Table D for women requires merely the note that Nos. 1 to 68 represent the original series, No. 69 the only woman included in the first supplementary series, and numbers 70 to 103 the individuals of the second supplementary series. In all calculations individual 69 has been treated with the second supplementary series, and to avoid confusion in discussion *both* have been consistently referred to as the supplementary series.

The table for men, C, is somewhat more complicated. Nos. 1 to 16 are the athletes, Nos. 17 to 27 the vegetarians, while Nos. 28 to 89 are the "other males," that is the non-athletic and non-vegetarian men of the original Nutrition Laboratory series. From this original series of 89 men Gephart and Du Bois have made a selection of 72 upon which they have based certain calculations. The key numbers and initials of the 17 which they have discarded are given on page 34. Nos. 90 to 117 represent the first supplementary series and Nos. 118 to 136 the second supplementary series.

After the calculations for this volume were completed, it was discovered that through a change in the key letters used to designate the subjects, T. H. Y. and T. J. (Nos. 20 and 129) are the same individual. Since the measurements were made at 23 and 27 years respectively, and since body-weight and body-surface-area differ slightly at these two periods, he has been treated as a different individual in the two series. The ages as originally submitted were 22 and 28 years. The actual date of birth (available since the calculations were completed) gives 23 and 27 years, as more nearly the ages at the time the observations were made. The constants have been allowed to stand as computed from the values given in the table, since the change could hardly have made a sensible difference in the end results.

TABLE A.—*Fundamental data for male infants.*

No.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters, Lissauer.	Pulse-rate.	Heat-production per 24 hours.		
		Days.	Periods.					Total calories.	Calories per kilogram.	Calories per square meter.
3	2½ days	2	2	3.63	52	0.243	97	166	46	685
5	7 hrs.	1	1	3.82	52.5	0.252	112	137	36	544
6	3½ days	2	3	4.32	52	0.273	116	191	44	697
8	2 days	2	3	3.48	51	0.236	117	160	45	673
10	2 days	2	3	3.45	52	0.235	116	162	48	694
15	4 days	3	3	3.64	50	0.243	122	162	44	665
18	7 days	1	2	2.84	50.5	0.207	105	108	38	519
19	1½ days	2	3	3.50	53	0.237	114	155	44	653
25	4 days	2	3	3.32	51.5	0.229	123	158	47	686
27	4 days	2	2	3.58	52	0.240	111	169	48	703
30	2 days	3	4	3.33	51	0.230	114	144	43	623
31	4 days	1	2	3.56	53.5	0.239	117	158	45	662
32	2½ days	2	3	3.42	47.5	0.234	116	140	41	604
33	5 days	2	2	3.73	52	0.248	129	153	41	617
36	21 hrs.	1	1	3.33	53	0.230	129	154	46	670
46	5 hrs.	1	2	3.83	51.5	0.252	126	152	40	603
47	5 hrs.	1	2	3.51	52	0.237	107	143	41	601
51	2 days	2	2	3.73	52.5	0.248	96	154	42	623
53	2 days	1	2	2.87	47.5	0.209	126	143	50	684
54	1½ days	1	2	3.31	50	0.229	106	129	39	563
55	16 hrs.	1	2	3.45	50	0.235	124	151	44	641
56	4 days	3	4	3.19	51.5	0.224	121	150	47	669
57	22 hrs.	2	3	3.75	54	0.249	105	153	40	611
60	4½ days	1	2	3.60	52	0.241	117	149	42	617
61	2½ hrs.	1	2	3.26	49.5	0.226	121	123	38	542
62	3 days	3	3	3.30	49.5	0.228	116	134	41	588
66	14 hrs.	1	2	3.19	51	0.224	103	122	38	543
67	3 days	2	3	4.74	54	0.291	122	193	41	669
68	4 days	2	3	2.12	46	0.170	113	103	48	604
69	19 hrs.	2	3	3.44	50	0.235	110	142	42	609
70	2 days	2	2	3.56	51	0.239	109	153	43	640
71	3 days	2	2	3.96	53.5	0.258	106	172	44	667
72	2½ days	1	2	3.29	50.5	0.228	110	157	48	687
73	7 hrs.	1	2	3.63	50	0.243	106	164	45	673
74	2 days	1	2	3.63	52	0.243	94	156	43	640
75	1½ days	1	2	2.65	47.5	0.198	100	132	50	664
76	13 hrs.	1	2	3.16	50	0.222	101	137	44	618
78	12 hrs.	1	2	2.48	47	0.189	101	109	44	577
80	3 hrs.	1	1	3.47	51.5	0.236	109	128	37	542
82	3 hrs.	1	1	2.74	49	0.202	101	95	35	470
83	3 hrs.	1	2	3.73	52	0.248	131	148	40	597
85	9 hrs.	1	1	3.52	52	0.238	109	144	41	605
87	3½ hrs.	2	2	3.94	51	0.257	118	146	37	567
89	8 hrs.	1	1	3.24	49.5	0.226	107	124	38	549
90	2½ days	2	3	3.00	50	0.214	86	138	46	641
93	4 hrs.	1	3	3.53	50.5	0.238	127	136	39	573
94	3½ hrs.	1	1	3.20	50	0.224	117	136	43	607
99	2½ hrs.	1	1	3.58	51.5	0.240	103	122	34	508
100	6½ hrs.	1	1	4.65	54	0.287	130	186	40	648
101	5½ hrs.	1	1	3.88	51.5	0.254	109	126	32	496
104	3 hrs.	1	1	3.32	51	0.229	107	105	32	459

TABLE B.—*Fundamental data for female infants.*

No.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters, Lissauer.	Pulse-rate.	Heat-production per 24 hours.		
		Days.	Periods.					Total calories.	Calories per kilogram.	Calories per square meter.
2	6½ days	2	2	3.80	53	0.251	99	152	40	606
4	2 days	2	3	3.28	46.5	0.227	105	139	43	612
9	2 days	1	2	4.04	51	0.262	109	178	44	677
12	5 days	2	2	4.17	52.5	0.267	112	171	41	639
13	2 days	3	4	3.25	50	0.226	113	138	43	612
16	2½ days	4	4	4.03	53	0.261	113	175	44	670
17	15 hrs.	1	2	3.66	52.5	0.244	118	174	48	713
20	3½ days	1	2	3.54	52	0.239	110	153	43	638
21	2 days	1	2	2.92	50	0.211	121	136	47	645
22	2½ days	1	2	2.72	49	0.201	114	128	47	635
26	5 days	2	3	3.46	50	0.235	113	151	44	645
29	2½ days	3	4	3.37	50	0.232	112	150	45	652
34	2 days	1	2	2.90	50.5	0.210	115	134	47	638
35	4 days	3	4	4.33	54	0.274	109	175	41	640
37	13 hrs.	1	2	2.49	46.5	0.189	119	99	40	522
38	1½ days	1	2	3.90	51.5	0.255	127	156	40	610
39	9 hrs.	1	1	2.95	50	0.212	105	113	38	533
40	4½ days	2	3	2.78	49.5	0.204	111	134	48	655
42	3 days	2	4	3.95	54	0.258	113	176	45	684
43	2 days	1	1	3.62	50	0.242	119	165	46	682
44	2 hrs.	1	2	3.57	51	0.240	103	136	38	567
45	1 day	2	3	2.56	46.5	0.193	110	107	43	553
48	6 days	1	2	4.52	54.5	0.282	132	188	42	667
49	4 days	1	2	2.75	47.5	0.203	114	130	47	638
50	1 day	1	1	2.75	48.5	0.203	89?	142	52	700
52	2½ days	3	4	3.54	50	0.239	114	138	39	579
58	1 day	2	4	3.01	49	0.215	111	139	46	647
59	1½ days	2	2	3.60	52	0.241	112	150	42	621
63	3 days	1	2	2.37	47.5	0.183	125	109	46	596
64	7 hrs.	1	2	3.37	48	0.232	98	128	38	552
65	2 days	2	3	2.63	49	0.197	116	127	48	644
79	4 hrs.	1	2	4.14	52.5	0.266	116	153	37	575
81	4 hrs.	1	1	3.29	50	0.228	114	167	51	732
84	2½ hrs.	1	2	4.11	54	0.264	109	133	32	504
86	6 hrs.	1	1	3.32	51	0.229	103	120	36	524
88	9 hrs.	1	2	2.62	47.5	0.196	96	122	47	623
91	13 hrs.	1	1	3.33	49.5	0.230	113	140	42	609
92	4 hrs.	1	1	3.78	51	0.250	112	157	42	628
95	5½ hrs.	1	1	2.84	46.5	0.207	123	100	35	483
96	3½ hrs.	1	1	3.23	51.5	0.225	99	113	35	502
97	4½ hrs.	1	2	2.82	48	0.206	113	112	40	542
98	5 hrs.	1	3	2.86	47.5	0.208	102	98	35	471
103	2½ hrs.	1	1	3.29	49	0.228	125	130	40	570

TABLE C.—*Fundamental data for men.*

No.	Subject.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters.		Pulse-rate.	Gaseous exchange per minute.		Gaseous exchange per kilogram per minute.		Heat-production per 24 hours.				Observer.
			Days.	Periods.			By Meeh formula.	By Du Bois height-weight chart.		Carbon-dioxide in c.c.	Oxygen in c.c.	Carbon-dioxide in c.c.	Oxygen in c.c.	Total calories.	Calories per kilo.	Calories per sq. m., Meeh.	Calories per sq. m., height-weight chart.	
1	F. G. R.	20	4	8	74.0	179	2.17	1.92	61	242	267	3.27	3.61	1914	25.9	882	997	Smith.
2	W. S.	22	3	6	88.5	165	2.45	1.96	54	241	289	2.72	3.27	2017	22.8	823	1029	Smith.
3	M. H. K. ...	19	2	3	79.0	188	2.27	2.04	67	243	276	3.07	3.49	1944	24.6	856	953	Smith.
4	E. G.	20	6	11	78.9	184	2.26	2.01	59	262	302	3.32	3.83	2126	27.0	940	1058	Smith.
5	D. H. W. ...	22	3	4	82.1	186	2.33	2.06	58	245	291	2.99	3.55	2034	24.8	873	987	Smith.
6	J. H. R. ...	23	3	6	82.2	187	2.33	2.07	65	243	282	2.95	3.43	1978	24.1	849	956	Smith.
7	H. W.	19	1	2	108.9	198	2.81	2.43	71	326	361	2.99	3.31	2559	23.5	911	1053	Smith.
8	W. F. M. ...	21	7	12	62.4	180	1.94	1.80	78	221	259	3.54	4.16	1816	29.1	936	1009	Smith.
9	M. A. M. ...	29	53	157	66.0	177	2.01	1.81	62	206	242	3.12	3.67	1695	25.7	843	936	Cathcart.
10	C. D. R. ...	22	3	6	74.0	173	2.17	1.87	63	238	270	3.22	3.65	1908	25.8	879	1020	Smith.
11	P. D. F. ...	23	3	6	71.2	176	2.11	1.87	54	219	259	3.07	3.64	1810	25.4	858	968	Smith.
12	H. R. W. ...	24	3	6	73.9	175	2.17	1.89	63	222	264	3.00	3.57	1842	24.9	848	975	Smith.
13	R. D. S. ...	21	3	6	63.5	170	1.96	1.74	57	205	228	3.23	3.60	1619	25.5	826	930	Smith.
14	M. Y. B. ...	20	6	12	63.5	172	1.96	1.75	62	207	238	3.26	3.75	1677	26.4	856	958	Smith.
15	C. J. D. ...	27	3	6	56.7	160	1.82	1.59	58	...	218	....	3.84	1524	26.9	838	958	Smith.
16	W. A. S. ...	21	5	10	56.3	169	1.81	1.65	60	190	223	3.37	3.96	1562	27.7	863	947	Smith.
17	F. E. M. ...	38	2	6	75.0	164	2.19	1.81	55	209	242	2.79	3.22	1698	22.7	775	938	Roth.
18	E. H. T. ...	25	2	7	64.7	170	1.98	1.75	70	173	217	2.67	3.35	1499	23.2	757	857	Roth.
19	L. H. W. ...	27	1	3	60.0	179	1.89	1.76	57	184	219	3.07	3.65	1530	25.5	810	869	Roth.
20	T. H. Y. ...	22	2	6	59.2	169	1.87	1.68	66	190	231	3.21	3.91	1605	27.2	861	955	Roth.
21	B. K.	39	1	3	58.2	178	1.85	1.72	..	166	200	2.85	3.44	1393	23.9	753	810	Roth.
22	E. J. W. ...	58	1	3	50.0	155	1.67	1.47	43	142	165	2.84	3.30	1158	23.2	693	788	Roth.
23	V. E. H. ...	21	1	3	49.3	163	1.66	1.51	53	157	198	3.18	4.02	1365	27.7	822	904	Roth.
24	Dr. P. R. ...	41	9	33	55.2	164	1.78	1.60	58	158	193	2.86	3.50	1341	24.3	753	838	Higgins.
25	B. N. C. ...	32	1	3	50.6	179	1.69	1.63	61	192	213	3.79	4.21	1510	29.8	893	926	Roth.
26	O. N. A. ...	25	1	3	55.4	171	1.79	1.64	66	177	224	3.19	4.04	1545	27.9	863	942	Roth.
27	W. B. L. ...	29	1	3	59.3	164	1.87	1.65	70	165	211	2.78	3.56	1451	24.5	776	955	Roth.

28	O. F. M....	24	2	6	85.8	171	2.40	1.98	57	209	265	2.44	3.09	1827	21.3	761	923	Emmes.
29	F. G. B.....	41	8	37	83.1	183	2.34	2.05	65	217	258	2.61	3.10	1802	21.7	770	879	Carpenter.
30	Prof. C.....	36	3	12	83.0	169	2.34	1.93	61	199	237	2.40	2.85	1655	19.9	707	856	Emmes.
31	H. F.......	63	1	4	82.1	166	2.33	1.90	68	180	236	2.19	2.87	1615	19.7	693	850	Carpenter.
32	W. A. M....	23	2	6	78.0	183	2.25	2.00	65	213	262	2.73	3.36	1816	23.3	807	908	Emmes.
33	Dr. M......	28	2	12	75.9	175	2.21	1.91	58	214	273	2.82	3.60	1877	24.7	849	983	Higgins.
34	M. Ba......	20	1	3	75.0	180	2.19	1.94	63	221	263	2.95	3.51	1837	24.5	839	947	Carpenter.
35	J. F. M.....	20	1	2	74.5	181	2.18	1.94	67	227	269	3.05	3.61	1879	25.2	862	969	Higgins.
36	F. A. R.....	32	3	13	74.4	163	2.18	1.80	57	205	244	2.76	3.28	1704	22.9	782	947	Carpenter.
37	W. J. T.....	22	4	12	74.2	183	2.17	1.96	59	206	256	2.78	3.45	1770	23.9	816	903	Carpenter.
38	J. P. C.....	23	4	14	73.7	169	2.16	1.83	53	186	218	2.52	2.96	1526	20.7	706	834	Emmes.
39	A. O. G.....	25	1	4	73.1	179	2.15	1.91	57	194	261	2.65	3.57	1776	24.3	826	930	Carpenter.
40	H. W. E....	23	2	7	73.0	168	2.15	1.82	49	190	222	2.60	3.04	1559	21.4	725	857	Carpenter.
41	C. B. S.....	26	26	75	71.1	179	2.11	1.89	63	202	244	2.84	3.43	1700	23.9	806	899	Higgins.
42	J. H. H.....	25	5	13	69.1	171	2.07	1.80	63	197	234	2.85	3.39	1634	23.6	789	908	Carpenter.
43	Dr. N. K. W.	35	1	3	68.4	166	2.06	1.76	50	196	219	2.87	3.20	1549	22.6	752	880	Emmes.
44	B. A. W....	26	2	7	67.9	174	2.05	1.82	59	229	280	3.37	4.12	1945	28.6	949	1069	Higgins.
45	K. H. A....	26	25	110	66.4	182	2.02	1.86	51	194	238	2.92	3.58	1654	24.9	819	889	Carpenter.
46	J. R........	27	12	57	66.0	182	2.01	1.86	64	201	241	3.05	3.65	1679	25.4	835	903	Emmes.
47	F. P. R.....	22	20	58	65.1	173	1.99	1.79	59	182	222	2.80	3.41	1543	23.7	775	862	Higgins.
48	J. J. C......	27	53	252	65.0	175	1.99	1.79	60	190	227	2.92	3.49	1585	24.4	796	885	Carpenter.
49	D. M.......	22	5	15	64.0	171	1.97	1.75	61	187	240	2.92	3.75	1651	25.8	838	943	Higgins.
50	M. J. S.....	24	13	42	63.7	170	1.96	1.74	61	195	237	3.06	3.72	1647	25.9	840	947	Carpenter.
51	E. P. C.....	35	3	12	63.2	185	1.95	1.85	50	171	216	2.71	3.42	1489	23.6	764	805	Carpenter.
52	R. G.......	23	4	16	62.7	173	1.94	1.76	63	194	227	3.09	3.62	1590	25.4	820	903	Carpenter.
53	U. R. B.....	27	1	3	62.6	173	1.94	1.76	52	179	220	2.86	3.51	1525	24.4	786	866	Higgins.
54	H. H. A....	22	28	81	62.3	164	1.93	1.68	66	179	213	2.87	3.42	1487	23.9	770	885	Higgins.
55	H. C. B....	27	2	4	62.0	173	1.93	1.74	59	192	239	3.10	3.85	1653	26.7	856	950	Higgins.
56	S. A. R.....	23	9	44	60.8	165	1.90	1.67	53	175	209	2.88	3.44	1460	24.0	768	874	Carpenter.
57	A. L........	40	4	12	60.6	171	1.90	1.71	73	191	225	3.15	3.71	1576	26.0	829	922	Carpenter.
58	W. G. J....	21	9	26	60.5	175	1.90	1.74	70	210	250	3.47	4.13	1746	28.9	919	1003	Higgins.
59	H. L. H....	26	35	120	60.5	172	1.90	1.72	68	200	244	3.31	4.03	1696	28.0	893	986	Emmes.
60	J. E. F.....	21	7	24	60.4	172	1.90	1.72	55	202	229	3.34	3.79	1616	26.8	851	940	Cathcart.
61	J. K. M....	24	27	103	60.4	173	1.90	1.72	57	182	223	3.01	3.69	1549	25.6	815	901	Carpenter.
62	H. B. R....	25	2	10	60.5	168	1.90	1.68	67	173	214	2.86	3.54	1487	24.6	783	885	Higgins.
63	J. B. T.....	20	11	43	60.1	171	1.89	1.70	65	209	251	3.48	4.18	1748	29.1	925	1028	Carpenter.
64	W. F. B....	32	5	16	60.1	168	1.89	1.68	54	199	233	3.31	3.88	1632	27.2	863	971	Carpenter.
65	H. B. L.....	20	5	18	60.0	173	1.89	1.72	65	190	229	3.17	3.82	1596	26.6	844	928	Carpenter.
66	L. E. E.....	31	31	144	59.8	176	1.88	1.74	58	204	245	3.41	4.10	1707	28.5	908	981	Riche.
67	F. M. M....	16	4	18	59.7	173	1.88	1.72	50	203	251	3.40	4.20	1739	29.1	925	1011	Carpenter.
68	Dr. S.......	43	5	13	58.5	181	1.86	1.75	56	153	193	2.62	3.30	1331	22.8	716	761	Higgins.

TABLE C.—*Fundamental data for men*—Continued.

No.	Subject.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters.		Pulse-rate.	Gaseous exchange per minute.		Gaseous exchange per kilogram per minute.		Heat-production per 24 hours.				Observer.
			Days.	Periods.			By Meeh formula.	By Du Bois height-weight chart.		Carbon-dioxide in c.c.	Oxygen in c.c.	Carbon-dioxide in c.c.	Oxygen in c.c.	Total calories.	Calories per kilo.	Calories per sq. m., Meeh.	Calories per sq. m., height-weight chart.	
69	D. J. M....	20	5	31	58.0	175	1.84	1.71	60	189	233	3.26	4.02	1615	27.8	878	944	Higgins.
70	H. F. T....	32	41	211	57.8	179	1.84	1.73	47	165	192	2.85	3.32	1348	23.3	733	779	Carpenter.
71	E. T. W....	22	4	12	57.8	169	1.84	1.67	68	171	213	2.96	3.69	1472	25.5	800	881	Higgins.
72	P. F. J.....	20	18	82	57.2	167	1.83	1.64	72	193	232	3.37	4.06	1616	28.3	883	985	Carpenter.
73	L. D. A....	19	2	6	57.1	171	1.83	1.67	61	188	220	3.29	3.85	1539	27.0	844	922	Roth.
74	A. G. E....	26	14	68	57.1	169	1.82	1.65	66	195	216	3.42	3.79	1531	26.9	841	928	Higgins.
75	R. I. C.....	26	2	9	56.8	184	1.82	1.76	62	194	244	3.42	4.30	1687	29.7	927	959	Emmes.
76	J. W. P.....	30	3	11	56.7	172	1.82	1.68	62	196	238	3.45	4.20	1654	29.2	909	985	Carpenter.
77	W. W. C....	17	2	4	56.3	172	1.81	1.67	64	199	232	3.54	4.12	1629	28.9	900	975	Smith.
78	J. C. C.....	22	2	7	56.1	173	1.80	1.68	51	179	219	3.19	3.90	1522	27.1	846	906	Carpenter.
79	C. H. H....	19	9	25	55.1	169	1.78	1.62	61	173	203	3.14	3.68	1421	25.8	798	877	Emmes.
80	I. A. F.....	24	3	18	54.9	156	1.78	1.53	68	190	232	3.46	4.23	1612	29.4	906	1054	Carpenter.
81	V. G.......	17	17	71	54.3	162	1.77	1.57	59	198	233	3.65	4.29	1632	30.1	922	1039	Carpenter.
82	A. F. G.....	24	1	3	53.9	175	1.76	1.65	61	178	207	3.30	3.84	1453	27.0	826	881	Emmes.
83	M. B.......	27	3	9	53.6	160	1.75	1.54	61	170	210	3.17	3.92	1455	27.1	831	945	Carpenter.
84	L. E. A.....	30	1	3	52.2	174	1.72	1.62	67	191	219	3.66	4.20	1541	29.5	896	951	Roth.
85	B. M. K....	27	1	4	51.4	163	1.70	1.55	75	164	234	3.19	4.55	1579	30.7	929	1019	Emmes.
86	J. J. G.....	21	6	20	50.2	164	1.68	1.53	57	175	203	3.49	4.04	1425	28.4	848	931	Carpenter.
87	F. P.......	17	1	3	49.3	161	1.66	1.50	60	188	229	3.81	4.65	1591	32.3	958	1061	Roth.
88	T. M. C....	35	17	93	48.5	165	1.64	1.51	69	156	185	3.22	3.81	1292	26.6	788	856	Emmes.
89	J. H........	26	6	12	46.3	154	1.59	1.42	68	153	173	3.31	3.73	1223	26.4	769	861	Smith.
90	Dr. W. W. P.	32	2	6	92.0	187	2.51	2.18	63	213	273	2.32	2.97	1878	20.4	748	861	Means.
91	E. M.......	24	1	2	77.4	169	2.24	1.88	79	221	294	2.86	3.80	2006	25.9	896	1067	Higgins.
92	M. J. M....	24	3	22	73.3	176	2.16	1.89	59	200	247	2.73	3.37	1712	23.4	793	906	Carpenter.
93	J. T. F.....	25	4	12	71.3	184	2.12	1.93	52	210	265	2.95	3.72	1827	25.6	862	947	Higgins.
94	H. R. R....	19	8	32	70.0	185	2.09	1.93	73	215	269	3.07	3.84	1860	26.6	890	964	Miss Tompkins.
95	E. B. F.....	24	2	8	69.7	178	2.09	1.87	65	232	285	3.33	4.09	1980	28.4	947	1059	Carpenter.

96	A. J. O.	30	30	122	69.5	180	2.08	1.88	60	212	248	3.05	3.57	1741	25.1	837	926	Miss Tompkins.
97	Dr. R. F. . . .	26?	5	15	68.2	178	2.06	1.86	59	186	237	2.73	3.48	1634	24.0	793	878	Higgins.
98	J. H. G.	20	1	4	67.2	185	2.04	1.89	68	204	247	3.04	3.68	1721	25.6	843	911	Emmes.
99	Dr. F. W. P.	33	3	8	66.7	175	2.03	1.82	64	189	228	2.83	3.42	1588	23.8	782	873	Higgins.
100	A. F.	25	5	14	66.5	175	2.02	1.81	63	218	261	3.28	3.92	1818	27.3	900	1004	Higgins.
101	H. G. E. . . .	21	13	38	65.8	183	2.01	1.87	57	220	265	3.34	4.03	1846	28.1	918	987	Higgins.
102	J. C.	32	1	3	64.7	173	1.98	1.78	63	179	247	2.77	3.82	1672	25.8	844	939	Higgins.
103	J. L. S.	21	4	14	64.4	170	1.98	1.75	64	191	226	2.97	3.51	1583	24.6	799	905	Miss Corson.
104	W. H. D. . . .	33	2	7	64.3	178	1.98	1.81	62	198	240	3.08	3.73	1672	26.0	844	924	Miss Tompkins.
105	Dr. E. J. . . .	45	4	10	61.4	178	1.92	1.77	64	159	197	2.59	3.21	1365	22.2	711	771	Miss Tompkins.
106	T. J. L.	21	2	7	59.8	170	1.88	1.69	57	177	208	2.96	3.48	1457	24.4	775	862	Emmes.
107	A. J. G.	22	2	4	58.2	185	1.85	1.78	82	196	233	3.37	4.00	1627	28.0	879	914	Emmes.
108	H. W. F. . . .	25	21	79	57.6	174	1.84	1.70	60	173	208	3.00	3.61	1449	25.2	788	852	Miss Tompkins.
109	K. H. B. . . .	26	5	15	57.4	173	1.83	1.69	57	180	215	3.14	3.75	1502	26.2	821	889	Miss Tompkins.
110	E. D. B. . . .	23	4	10	56.9	173	1.82	1.68	58	183	215	3.22	3.78	1506	26.5	827	896	Emmes.
111	A. S.	19	3	12	56.4	174	1.81	1.68	56	177	201	3.14	3.56	1418	25.1	783	844	Miss Tompkins.
112	J. E. L.	21	16	69	55.9	174	1.80	1.67	54	171	209	3.06	3.74	1452	26.0	807	869	Miss Corson.
113	T. H. H. . . .	29	17	64	54.5	171	1.77	1.63	59	181	207	3.32	3.80	1457	26.7	823	894	Miss Tompkins.
114	S. I.	23	1	3	54.0	169	1.76	1.61	64	157	206	2.91	3.81	1410	26.1	801	876	Carpenter.
115	J. V. M. . . .	22	7	21	49.7	162	1.67	1.51	61	177	208	3.56	4.19	1457	29.3	872	965	Higgins.
116	W. K.	29	28	128	49.2	162	1.65	1.51	57	159	187	3.23	3.80	1310	26.6	794	868	Miss Tompkins.
117	E. S. M. . . .	24	1	3	33.2	148	1.27	1.19	71	122	142	3.67	4.28	997	30.0	785	838	Miss Corson.
118	F. K.	18	1	1	83.1	183	2.34	2.05	. .	221	284	2.66	3.42	1953	23.5	835	953	Roth.
119	T. A.	30	1	3	74.0	171	2.17	1.86	. .	201	225	2.72	3.04	1591	21.5	733	855	Roth.
120	Dr. A. H. R.	39	3	10	71.9	170	2.13	1.83	. .	184	225	2.56	3.13	1563	21.7	734	854	Roth.
121	T. N. R. . . .	21	2	3	69.7	175	2.09	1.84	. .	237	280	3.40	4.02	1961	28.1	938	1066	Roth.
122	T. C. D. . . .	24	1	3	68.6	180	2.06	1.87	. .	231	258	3.37	3.76	1829	26.7	888	978	Roth.
123	Prof. W. M. .	32	1	4	68.2	179	2.06	1.86	64	212	236	3.11	3.46	1673	24.5	812	899	Miss Corson.
124	W. H. B. . . .	22	1	3	67.3	170	2.04	1.78	. .	222	240	3.30	3.57	1714	25.5	840	963	Roth.
125	F. W. R. . . .	21	2	2	65.3	169	2.00	1.75	. .	207	234	3.17	3.58	1651	25.3	826	943	Roth.
126	R. R. D. . . .	21	1	1	63.6	174	1.96	1.77	. .	235	289	3.70	4.54	2003	31.5	1022	1132	Roth.
127	Dr. C. C. W.	26	3	7	61.6	180	1.92	1.79	. .	182	233	2.95	3.78	1602	26.0	834	895	Roth.
128	G. H.	23	1	3	61.4	171	1.92	1.72	. .	202	225	3.29	3.66	1595	26.0	831	927	Roth.
129	T. J.	28	1	2	60.5	172	1.90	1.72	. .	179	210	2.96	3.47	1471	24.3	774	855	Roth.
130	L. M. S. . . .	28	1	3	58.9	166	1.86	1.65	. .	176	208	2.99	3.53	1457	24.7	783	883	Roth.
131	I. B. S.	24	2	8	57.9	168	1.84	1.66	66	190	220	3.28	3.80	1544	26.7	839	930	Miss Corson.
132	W. A. W. . . .	30	11	19	55.0	172	1.78	1.65	. .	165	211	3.00	3.84	1451	26.4	815	879	Roth.
133	C. J. J.	43	1	2	53.4	169	1.75	1.60	. .	195	211	3.65	3.95	1503	28.1	859	939	Roth.
134	R. B.	62	2	8	74.8	179	2.19	1.93	72	195	227	2.61	3.03	1594	21.3	728	826	Miss Corson.
135	M. M.	57	2	7	60.6	168	1.90	1.69	48	197	225	3.25	3.71	1588	26.2	836	940	Miss Corson.
136	A. W. C. . . .	61	1	4	60.3	170	1.89	1.70	51	169	203	2.80	3.37	1414	23.4	748	832	Miss Corson.

TABLE D.—*Fundamental data for women.*

No.	Subject.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters.		Pulse-rate.	Gaseous exchange per minute.		Gaseous exchange per kilogram per minute.		Heat-production per 24 hours.				Observer.
			Days.	Periods.			By Meeh formula.	By Du Bois height-weight chart.		Carbon-dioxide in c.c.	Oxygen in c.c.	Carbon-dioxide in c.c.	Oxygen in c.c.	Total calories.	Calories per kilogram.	Calories per square meter, Meeh formula.	Calories per square meter, height-weight chart.	
1	Dr. M. D.	44	1	2	93.6	165	2.54	2.01	61	202	256	2.16	2.74	1765	18.9	695	878	Roth.
2	Miss O. A.	21	1	3	90.2	164	2.48	1.96	55	203	254	2.25	2.82	1756	19.5	708	896	Roth.
3	Miss H. H	21	2	6	83.3	161	2.44	1.92	68	190	228	2.16	2.58	1591	18.1	652	829	Emmes.
4	Mrs. H. D.	42	2	7	80.1	157	2.29	1.81	65	184	233	2.29	2.91	1606	20.1	702	887	Emmes.
5	Miss C. Z.	39	2	6	67.2	170	2.04	1.78	68	176	220	2.62	3.28	1521	22.7	747	854	Roth.
6	Miss S.	27	2	5	65.5	171	2.00	1.77	54	178	202	2.71	3.09	1426	21.8	713	806	Carpenter.
7	Miss C. H.	25	2	7	63.4	166	1.96	1.71	65	156	207	2.45	3.27	1413	22.3	722	826	Emmes.
8	Miss A. K.	23	2	6	63.2	171	1.95	1.74	62	165	202	2.62	3.20	1402	22.2	717	806	Emmes.
9	Miss A. G.	21	2	7	63.0	161	1.95	1.66	63	153	192	2.44	3.04	1324	21.1	679	798	Emmes.
10	Miss V. A.	21	2	6	62.9	168	1.95	1.72	62	167	188	2.66	2.99	1330	21.2	682	773	Emmes.
11	Miss C.	22	2	6	61.9	168	1.93	1.71	75	177	203	2.85	3.28	1427	23.1	739	835	Emmes.
12	Miss K. K.	21	1	4	61.5	154	1.92	1.60	73	...	238	....	3.87	1666	27.1	868	1041	Emmes.
13	Dr A. B.	32	1	4	60.3	163	1.89	1.65	61	197	207	3.27	3.43	1486	24.6	786	901	Emmes.
14	Miss L. G.	38	2	6	59.5	159	1.88	1.61	60	134	173	2.25	2.91	1187	20.0	633	737	Emmes.
15	Miss B. W.	22	2	6	59.4	162	1.87	1.63	84	180	223	3.03	3.76	1546	26.0	827	948	Emmes.
16	Miss L. U.	23	2	7	59.3	169	1.87	1.68	55	176	207	2.96	3.50	1448	24.4	774	862	Emmes.
17	Miss M. W.	25	2	8	58.6	167	1.86	1.66	68	168	206	2.86	3.52	1429	24.4	768	861	Emmes.
18	Miss M. P.	28	2	7	58.1	168	1.85	1.67	65	170	222	2.92	3.82	1518	26.2	823	909	Emmes.
19	Mrs. E. B.	53	1	3	58.0	163	1.84	1.62	73	171	202	2.95	3.48	1415	24.4	769	873	Roth.

20	Miss M. M.	18	1	4	57.9	164	1.84	1.63	67	191	207	3.30	3.58	1475	25.4	801	905	Emmes.
21	Miss E. P.	23	2	6	57.7	175	1.84	1.70	73	166	207	2.87	3.59	1430	24.9	780	841	Emmes.
22	Miss L. K.	22	2	6	56.8	166	1.82	1.63	73	153	199	2.70	3.51	1365	24.1	750	837	Roth.
23	Miss E. A.	15	2	5	56.8	157	1.82	1.57	65	205	231	3.61	4.06	1630	28.7	896	1038	Emmes.
24	Miss A. M.	20	2	8	56.8	152	1.82	1.53	54	155	192	2.73	3.39	1329	23.4	733	869	Emmes.
25	Miss J. C.	22	2	6	55.1	162	1.78	1.58	51	157	198	2.85	3.59	1363	24.8	764	863	Emmes.
26	Miss G. L.	21	2	7	55.0	166	1.78	1.61	75	173	214	3.15	3.89	1480	27.0	832	919	Emmes.
27	Mrs. D. C.	36	3	8	54.9	153	1.78	1.51	70	160	182	2.91	3.32	1276	23.3	719	845	Carpenter.
28	Miss M. T.	20	2	7	54.5	164	1.77	1.59	74	147	196	2.76	3.60	1359	25.0	770	855	Emmes.
29	Miss F. K.	18	2	5	54.1	164	1.76	1.59	67	157	179	2.89	3.31	1262	23.4	716	794	Carpenter.
30	Miss J. N. B.	26	1	3	53.8	160	1.75	1.55	78	134	178	2.49	3.31	1215	22.6	694	784	Roth.
31	Miss L. T.	31	2	8	53.6	155	1.75	1.51	64	152	178	2.84	3.33	1247	23.3	713	826	Emmes.
32	Miss F. E.	22	2	8	53.1	162	1.74	1.56	82	161	202	3.04	3.80	1391	26.2	799	892	Emmes.
33	Miss L.	25	2	6	52.4	168	1.73	1.59	69	162	188	3.09	3.59	1321	25.2	763	831	Emmes.
34	Miss A. D.	37	2	5	52.3	166	1.72	1.57	88	159	196	3.04	3.74	1355	26.0	788	863	Emmes.
35	Miss B.	21	2	6	52.2	158	1.72	1.51	78	173	202	3.31	3.88	1415	27.2	823	937	Emmes.
36	Miss R. M.	16	2	6	52.1	162	1.72	1.54	70	159	195	3.04	3.75	1353	26.0	787	879	Emmes.
37	Miss L. J.	24	1	3	51.8	159	1.71	1.52	52	142	179	2.74	3.46	1235	23.8	722	813	Emmes.
38	Mrs. A.	29	1	3	51.6	163	1.71	1.55	75	166	205	3.22	3.97	1421	27.5	831	917	Carpenter.
39	Miss J. M.	16	1	3	51.4	158	1.70	1.51	77	....	220	....	4.28	1541	30.0	906	1021	Emmes.
40	Miss J. B.	27	2	6	51.1	163	1.70	1.54	76	146	183	2.86	3.58	1265	24.8	746	821	Emmes.
41	Miss R. A.	21	2	6	50.8	155	1.69	1.48	77	161	184	3.18	3.62	1293	25.5	765	874	Emmes.
42	Miss M. C.	16	2	6	50.6	162	1.69	1.52	83	145	185	2.86	3.66	1273	25.2	756	838	Emmes.
43	Miss E. C.	25	2	8	50.5	164	1.68	1.53	71	155	192	3.07	3.80	1327	26.3	788	867	Emmes.
44	Miss I. B.	18	2	5	50.1	166	1.67	1.54	70	160	173	3.20	3.46	1235	24.7	737	802	Carpenter.
45	Miss E. S.	25	1	4	50.0	164	1.67	1.53	65	154	195	3.08	3.90	1345	26.9	806	879	Emmes.
46	Miss C. B.	24	2	6	49.8	162	1.67	1.52	75	168	205	3.38	4.16	1419	28.6	850	934	Emmes.
47	Miss G. J.	22	2	6	49.7	160	1.67	1.50	63	128	166	2.58	3.34	1139	23.0	684	759	Emmes.
48	Miss D. W.	19	3	8	49.4	160	1.66	1.49	61	153	187	3.10	3.79	1300	26.3	786	872	Emmes.
49	Miss M. H.	27	2	5	49.1	151	1.65	1.43	66	135	171	2.74	3.49	1178	24.0	712	824	Roth.
50	Miss C. L.	21	1	2	49.1	151	1.65	1 43	78	153	195	3.12	3.97	1341	27.3	813	938	Roth
51	Mrs. C. E.	74	1	3	48.9	161	1.65	1.51	63	122	160	2.49	3.27	1095	22.4	663	725	Emmes.
52	Miss V. M.	24	1	3	48.9	162	1.65	1.50	70	149	198	3.05	4.05	1351	27 6	819	901	Emmes.
53	Miss M. S.	24	2	7	48.5	159	1.64	1.48	74	167	216	3.45	4.45	1480	30.5	905	1000	Emmes.
54	Miss G. F.	27	2	6	48.5	155	1.64	1.45	70	140	180	2.88	3.70	1233	25.4	754	850	Emmes.
55	Miss K. M.	22	2	4	48.2	161	1.63	1 49	69	161	184	3.34	3.82	1294	26.9	794	868	Carpenter.

TABLE D.—*Fundamental data for women*—Continued.

No.	Subject.	Age.	Observations.		Body-weight in kilograms.	Height in centimeters.	Body-surface in square meters.		Pulse-rate.	Gaseous exchange per minute.		Gaseous exchange per kilogram per minute.		Heat-production per 24 hours.				Observer.
			Days.	Periods.			By Meeh formula.	By Du Bois height-weight chart.		Carbon-dioxide in c.c.	Oxygen in c.c.	Carbon-dioxide in c.c.	Oxygen in c.c.	Total calories.	Calories per kilogram.	Calories per square meter, Meeh formula.	Calories per square meter, height-weight chart.	
56	Miss L. B.	27	1	3	47.0	167	1.60	1.51	66	136	169	2.89	3.60	1168	24.9	730	774	Roth.
57	Miss E. T.	22	2	9	46.7	164	1.60	1.50	87	151	195	3.24	4.17	1336	28.6	838	891	Emmes.
58	Miss H. T.	25	2	6	45.0	159	1.56	1.43	80	156	203	3.47	4.51	1393	30.9	896	974	Emmes.
59	Miss R. W.	21	1	3	45.0?	153	1.56	1.40	75	141	186	3.13	4.13	1273	28.3	816	909	Emmes.
60	Mrs. A. L.	29	1	3	44.9	159	1.56	1.43	66	147	184	3.27	4.10	1272	28.3	815	890	Roth.
61	Miss M. J.	27	1	3	44.8	157	1.55	1.41	58	137	172	3.06	3.84	1189	26.5	767	843	Roth.
62	Miss J.	24	5	14	43.0	159	1.51	1.41	66	139	165	3.25	3.85	1158	26.9	766	821	Carpenter.
63	Miss A. C.	38	2	6	42.6	165	1.50	1.44	69	138	168	3.24	3.94	1168	27.4	779	811	Emmes.
64	Miss D. A.	19	1	3	41.5	154	1.48	1.36	76	136	176	3.28	4.24	1207	29.1	816	888	Roth.
65	Miss E. W.	24	2	6	40.5	157	1.45	1.35	82	153	183	3.78	4.51	1273	31.4	878	943	Emmes.
66	Miss J. T.	36	1	3	40.0	168	1.44	1.41	65	139	186	3.48	4.65	1269	31.7	881	900	Roth.
67	Mrs. S. C.	52	2	5	37.4	155	1.38	1.30	65	122	140	3.25	3.75	985	26.4	714	758	Carpenter.
68	Mrs. A. A.	43	1	2	35.6	170	1.33	1.36	72	119	169	3.34	4.75	1141	32.1	853	839	Carpenter.
69	Miss M.	24	2	8	56.6	160	1.81	1.58	64	158	186	2.79	3.29	1302	23.0	719	824	Miss A. Johnson.
70	Mrs. G. B	44	2	8	82.6	176	2.34	1.99	63	164	199	1.99	2.41	1383	16.7	591	695	Miss Corson.
71	Mrs. W.	44	1	4	72.0	164	2.13	1.78	..	170	203	2.36	2.82	1418	19.7	666	797	Miss Corson.
72	Mrs. M. H.	34	2	7	70.2	160	2.10	1.74	..	176	215	2.51	3.06	1494	21.3	711	859	Roth.
73	Mrs. O. C.	35	1	3	66.8	163	2.03	1.72	..	182	229	2.72	3.43	1579	23.6	778	918	Roth
74	Miss E. R.	22	1	1	62.7	169	1.94	1.72	..	195	245	3.11	3.91	1694	27.0	873	985	Roth.

75	Miss W.	38	1	4	61.6	171	1.92	1.72	..	161	192	2.61	3.12	1341	21.8	698	780	Miss Corson.
76	Mrs. A. N. D.	41	1	4	60.7	161	1.90	1.64	65	150	179	2.47	2.95	1250	20.6	658	762	Miss Corson.
77	Mrs. M. C.	45	1	4	60.1	163	1.89	1.65	78	189	232	3.14	3.86	1608	26.8	851	975	Miss Corson.
78	Mrs. M. F.	26	1	3	59.5	156	1.88	1.59	..	193	236	3.24	3.97	1640	27.6	872	1031	Roth.
79	Miss M. Sx.	19	2	2	59.1	170	1.87	1.68	..	199	236	3.37	3.99	1648	27.9	881	981	Roth.
80	Miss I. A. B.	18	2	7	54.8	161	1.78	1.57	70	170	198	3.10	3.61	1390	25.4	781	885	Miss Corson.
81	Miss Ma. H.	20	1	3	54.5	162	1.77	1.57	80	174	202	3.19	3.71	1418	26.0	801	903	Miss Corson.
82	Mrs. M.	37	2	8	53.8	169	1.75	1.61	61	148	171	2.75	3.18	1203	22.4	687	747	Miss Corson.
83	Mrs. A. R. K.	25	1	3	53.5	156	1.75	1.52	..	158	197	2.95	3.68	1362	25.5	778	896	Roth.
84	Miss A. E. M.	22	2	8	52.5	158	1.73	1.52	60	139	161	2.65	3.07	1130	21.5	653	743	Miss Corson.
85	Miss L. M.	32	1	1	50.0	157	1.67	1.48	..	166	199	3.32	3.98	1390	27.8	832	939	Roth.
86	Miss H. W.	24	1	4	49.1	160	1.65	1.49	61	136	166	2.77	3.38	1153	23.5	699	774	Miss Corson.
87	Mrs. M. M. C.	26	1	3	48.9	157	1.65	1.47	..	164	181	3.35	3.70	1287	26.3	780	876	Roth.
88	Mrs. E. Bx.	26	1	3	44.2	159	1.54	1.42	..	153	186	3.46	4.21	1292	29.2	839	910	Roth.
89	Miss Mi. M.	19	2	8	43.9	152	1.53	1.37	60	143	162	3.26	3.69	1143	26.0	747	834	Miss Corson.
90	Miss M. F.	22	1	4	41.3	157	1.47	1.36	73	134	152	3.24	3.68	1073	26.0	730	789	Miss Corson.
91	Mrs. M. B.	52	2	8	94.1	165	2.55	2.01	59	167	204	1.77	2.17	1417	15.1	556	705	Miss Corson.
92	Mrs. S. B.	55	2	8	78.6	169	2.26	1.89	..	161	191	2.05	2.43	1334	17.0	590	706	Miss Corson.
93	Mrs. R. H.	51	1	2	74.1	160	2.17	1.78	63	150	179	2.02	2.42	1250	16.9	576	702	Miss Corson.
94	Miss A. R. B.	60	1	2	71.9	167	2.13	1.81	59	162	204	2.25	2.84	1407	19.6	661	777	Miss Corson.
95	Mrs. T.	73	2	7	71.1	159	2.11	1.74	..	170	202	2.39	2.84	1411	19.8	669	811	Miss Corson.
96	Mrs. E. S. B.	56	2	8	70.1	164	2.09	1.77	63	160	183	2.28	2.61	1288	18.4	616	728	Miss Corson.
97	Miss T. M.	51	1	3	69.7	162	2.09	1.74	72	179	198	2.57	2.84	1404	20.1	672	807	Miss Corson.
98	Mrs. F. B.	58	1	4	68.4	162	2.06	1.74	92	176	205	2.57	3.00	1439	21.0	699	827	Miss Corson.
99	Mrs. R.	66	2	8	55.9	162	1.80	1.59	69	144	163	2.58	2.92	1150	20.6	639	723	Miss Corson.
100	Mrs. H.	57	2	8	54.0	161	1.76	1.56	67	139	155	2.57	2.87	1099	20.4	624	704	Miss Corson.
101	Mrs. L. C.	61	1	3	51.7	163	1.71	1.54	74	147	169	2.84	3.27	1189	23.0	695	772	Miss Corson.
102	Mrs. A. D.	50	1	4	48.0	156	1.63	1.45	58	142	162	2.96	3.38	1143	23.8	701	788	Miss Corson.
103	Miss Ab. D.	62	1	4	46.6	164	1.59	1.48	69	139	159	2.98	3.41	1119	24.0	704	756	Miss Corson.

The name of the observer in the final column of tables C and D fixes the laboratory at which the determinations were made. The places for the several observers are:

Carpenter, Nutrition Laboratory.
Cathcart, Nutrition Laboratory.
Miss Corson and Miss Johnson, New England Deaconess Hospital, Boston.
Emmes, Nutrition Laboratory.
Higgins, Nutrition Laboratory.
Means, Nutrition Laboratory.
Riche, Nutrition Laboratory.
Roth, Battle Creek Sanitarium.
Smith, Syracuse University.
Miss Tompkins, Nutrition Laboratory.

3. CRITERIA OF SUITABILITY OF MATERIALS DEALT WITH.

In this volume we have limited ourselves to the discussion of the metabolism of normal infants and of normal men and women.

It is important that the conception of *normal* as used in its present connection be made perfectly clear at the outset.

First of all, it means individuals in presumably good health.

Second, it is important to remember that, as we have used the term, the normal man is not an individual of any preconceived dimension, but a group of infants, men, or women representing the typical condition in the population.

The population at large has a certain mean, variability, and correlation of the measured parts of the human beings of which it is made up. We may, therefore, properly inquire whether the subjects studied at the Nutrition Laboratory agree reasonably well in correlation as well as in mean and variability with men and women as they have been studied by anthropologists. If they do agree in the physical characters for which a basis of comparison may be secured, within the limits of the probable errors of the determinations, we may feel confident that we are dealing with "representative," "typical," or "normal" men and women. If they differ too widely from the population at large, our data can not be considered altogether free from criticism.

In the following paragraphs we shall test the suitability of our material for the solution of problems concerning the physiology of a species, man, by ascertaining whether the sample of subjects dealt with is really representative of man in general in mean, variability, and correlation. In presenting our constants we are, of course, fully aware that these problems have been so extensively investigated by anthropologists and actuaries that no material contribution to the anthropological problems can be made on the basis of the number of individuals examined in this paper—a number which, while large from the physiological standpoint, is relatively small as compared with the more satisfactory anthropological series.

In the field of metabolism this course seems to have a particular justification. *Practically* the chief purpose of studies of the basal metabolism of normal subjects is to obtain a basis of comparison on which, in connection with studies in the experimental laboratory or

medical ward, conclusions may be drawn concerning the influence of special conditions, diets, or diseases upon metabolism. If results of the kind are to be of general value they must be universally valid and universally applicable. To be generally valid and broadly applicable the fundamental series should be based on individuals typical, not merely in average but in variability and correlation, of the population as a whole, rather than composed of individuals conforming to some personal preconception of "normal."

First of all we may present the actual statistical constants of the series of data which we have analyzed, and compare them with others based on larger numbers of individuals. Otherwise our own constants will not be discussed in great detail here, but form the basis of most of the calculations in the following chapters.

TABLE 5.—*Physical constants of male and female new-born infants.*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Male.				
Weight	51	3.459 ±0.0430	0.4554±0.0304	13.17±0.89
Pulse-rate	51	112.39 ±0.9524	10.08 ±0.6734	8.97±0.60
Total heat	51	144.55 ±1.974	20.90 ±1.396	14.46±0.99
Surface	51	0.2350±0.0020	0.0209±0.0014	8.88±0.59
Length	51	50.971 ±0.1665	1.763 ±0.1178	3.46±0.23
Female.				
Weight	43	3.336 ±0.0564	0.5483±0.0399	16.44±1.23
Pulse-rate	43	111.77 ±0.8705	8.46 ±0.6155	7.57±0.55
Total heat	43	140.37 ±2.389	23.22 ±1.689	16.54±1.24
Surface	43	0.2294±0.0026	0.0250±0.0018	10.89±0.80
Length	43	50.163 ±0.2265	2.202 ±0.1601	4.39±0.32
Both Sexes.				
Weight	94	3.403 ±0.0350	0.5036±0.0247	14.80±0.74
Pulse-rate	94	112.11 ±0.6525	9.38 ±0.4614	8.37±0.41
Total heat	94	142.64 ±1.537	22.09 ±1.087	15.49±0.78
Surface	94	0.2325±0.0016	0.0230±0.0011	9.88±0.49
Length	94	50.601 ±0.1408	2.025 ±0.0996	4.00±0.20

Consider first the problem of the variation and correlation in stature and weight in the series of subjects dealt with.

In doing this we shall lay emphasis upon variability as well as upon average dimensions. This is done because in selecting a series of measurements to be considered typical of the population at large it is quite as important that they represent the diversity of the population as that they show the proper average values.

The physical constants for our male and female infants are given in table 5.

For body-weight we have the following series of infants for comparison with our own.

Quetelet's classic series,[28] as reduced by Pearson,[29] gives the follow-

[28] Quetelet, Anthropométrie, 1871, p. 355.
[29] Pearson, The Chances of Death, 1897, 1, p. 307.

ing means, standard deviations, S. D., and coefficients of variation, C. V., for new-born male ($N = 63$) and female ($N = 56$) Belgian babies:

	Mean.	*S. D.*	*C. V.*
Male infants	3.289 ± 0.041	0.482 ± 0.029	14.66 ± 0.90
Female infants	3.053 ± 0.048	0.538 ± 0.034	17.62 ± 1.16

Reducing the data of the Anthropometric Committee's Report to the British Association,[30] we find for 451 boy infants and 466 girl infants:

	Mean.	*S. D.*	*C. V.*
Male infants	3.230 ± 0.016	0.508 ± 0.011	15.73 ± 0.36
Female infants	3.151 ± 0.015	0.480 ± 0.011	15.22 ± 0.35

From Stuttgart babies, 500 of each sex, Pearson deduced from Elsässer's measurements:

	Mean.	*S. D.*	*C. V.*
Male infants	3.233 ± 0.013	0.439 ± 0.009	13.57 ± 0.29
Female infants	3.151 ± 0.013	0.418 ± 0.009	13.28 ± 0.29

For the 1000 male and 1000 female new-born infants measured in the Lambeth Lying-in Hospital (London) Pearson [31] found:

	Mean.	*S. D.*	*C. V.*
Male infants	3.312 ± 0.011	0.519 ± 0.008	15.664 ± 0.242
Female infants	3.208 ± 0.010	0.456 ± 0.007	14.228 ± 0.219

Dr. Rood Taylor [32] has kindly allowed us to use his series of measurements of new-born infants, deposited at the Wistar Institute. These are very heterogeneous racially. We find for his 120 boys and 122 girls:

	Mean.	*S. D.*	*C. V.*
Male infants	3.496 ± 0.026	0.419 ± .018	11.99 ± 0.53
Female infants	3.368 ± 0.026	0.423 ± .018	12.57 ± 0.55

A comparison of our constants with those due to anthropologists is made in table 6. Here the signs of the differences show whether the constants for our babies are larger (+) or smaller (−) than those deduced by others.

Our infants show a slightly, but only slightly, greater average body-weight than either of the European series available for comparison. In 5 of the 8 comparisons the difference is less than 0.2 kilogram. In general the differences may be regarded as statistically significant in comparison with their probable errors. Our infants are slightly but not significantly lighter than Dr. Rood Taylor's series.

In variability, as measured in the absolute terms of the standard deviation and in the relative terms of the coefficient of variation, our series show an excellent agreement with those which have been published. In 7 of the 10 comparisons our standard deviations are slightly greater, while in 3 of the 10 comparisons they are slightly less than

[30] British Association Report, 1883, p. 286.
[31] Pearson, Proc. Roy. Soc. Lond., 1899, **66**, p. 25.
[32] Taylor, Am. Journ. Physiol., 1918, **45**, p. 569.

those due to other observers. The differences can be looked upon as statistically trustworthy in only 2 or 3 of the comparisons. Quite comparable results, as far as the smallness of the differences are concerned, are found for the coefficients of variation. In 5 of the 10 cases our series are relatively less variable and in 5 cases relatively more variable than those with which they are compared. The differences are statistically insignificant except in 3 or 4 cases. Thus our babies are slightly heavier than those measured by others except Taylor, but agree excellently in variability, both absolute and relative.

TABLE 6.—*Comparison of weight of Nutrition Laboratory babies with other series.*

Series.	Average.	$\frac{\text{Diff.}}{E_{diff.}}$	Standard deviation.	$\frac{\text{Diff.}}{E_{diff.}}$	Coefficient of variation.	$\frac{\text{Diff.}}{E_{diff.}}$
British association:						
Boys	$+0.229 \pm 0.046$	4.98	-0.053 ± 0.032	1.66	-2.56 ± 0.96	2.67
Girls	$+0.185 \pm 0.058$	3.19	$+0.068 \pm 0.041$	1.65	$+1.22 \pm 1.28$	0.95
Lambeth hospital:						
Boys	$+0.147 \pm 0.044$	3.34	-0.064 ± 0.031	2.06	-2.49 ± 0.92	2.71
Girls	$+0.128 \pm 0.067$	1.91	$+0.092 \pm 0.041$	2.24	$+2.22 \pm 1.25$	1.78
Belgian babies:						
Boys	$+0.170 \pm 0.059$	2.88	-0.027 ± 0.041	0.66	-1.49 ± 1.26	1.18
Girls	$+0.283 \pm 0.073$	3.88	$+0.010 \pm 0.052$	0.19	-1.18 ± 1.36	0.87
Stuttgart babies:						
Boys	$+0.226 \pm 0.045$	5.02	$+0.016 \pm 0.031$	0.52	-0.40 ± 0.94	0.43
Girls	$+0.185 \pm 0.057$	3.25	$+0.130 \pm 0.041$	3.17	$+3.16 \pm 1.26$	2.51
Dr. Taylor's series:						
Boys	-0.037 ± 0.050	0.74	$+0.036 \pm 0.035$	1.03	$+1.18 \pm 1.03$	1.15
Girls	-0.032 ± 0.062	0.52	$+0.125 \pm 0.044$	2.84	$+3.87 \pm 1.35$	2.87

For comparison with our results for length we may reduce the British Association data used for body-weight above. The constants for the 451 boy and 466 girl babies are:

	Mean.	*S. D.*	*C. V.*
Male infants	49.58 ± 0.11	3.48 ± 0.08	7.02 ± 0.16
Female infants	49.07 ± 0.10	3.25 ± 0.07	6.62 ± 0.15

We may also compare Pearson's constants for full-term male and female infants (1000 each) from the Lambeth Lying-in Hospital.[33] His results are:

	Mean.	*S. D.*	*C. V.*
Male infants	52.08 ± 0.07	3.38 ± 0.05	6.50 ± 0.10
Female infants	51.11 ± 0.06	2.99 ± 0.05	5.85 ± 0.09

Dr. Rood Taylor's infants give the following values for total length:

	Mean.	*S. D.*	*C. V.*
Male infants	51.18 ± 0.13	2.04 ± 0.09	3.98 ± 0.17
Female infants	50.07 ± 0.12	2.03 ± 0.09	4.08 ± 0.18

Comparison with our own series is made in table 7.

The average length of our babies is slightly greater than the British Association series but slightly less than the Lambeth Hospital series.

[33] Pearson, Proc. Roy. Soc. Lond., 1899, 66, p. 25.

Our boys are slightly shorter and our girls a little longer than Dr. Taylor's series, but the differences cannot be asserted to be significant. All our variabilities, both absolute and relative, as shown by the differences between standard deviations and coefficients of variation in table 7, are less than the British series, indicating that our measurements were made upon a group of infants somewhat more uniform. Our male infants are slightly less variable and our female infants somewhat more variable than Dr. Taylor's series.

TABLE 7.—*Comparison of length of Nutrition Laboratory babies with other series.*

Series.	Average.	Diff. / $E_{diff.}$	Standard deviation.	Diff. / $E_{diff.}$	Coefficient of variation.	Diff. / $E_{diff.}$
British association:						
Boys	$+1.39 \pm 0.20$	6.95	-1.72 ± 0.14	12.29	-3.56 ± 0.28	12.71
Girls	$+1.09 \pm 0.25$	4.36	-1.05 ± 0.17	6.18	-2.23 ± 0.36	6.19
Lambeth hospital:						
Boys	-1.11 ± 0.18	6.17	-1.62 ± 0.13	12.46	-3.04 ± 0.25	12.16
Girls	-0.95 ± 0.24	3.96	-0.79 ± 0.17	4.65	-1.46 ± 0.34	4.29
Dr. Taylor's series:						
Boys	-0.21 ± 0.21	1.00	-0.27 ± 0.15	1.83	-0.52 ± 0.29	1.79
Girls	$+0.10 \pm 0.26$	0.37	$+0.17 \pm 0.18$	0.93	$+0.33 \pm 0.37$	0.89

The correlations between stature (length) and weight in our infants are as follows:

For males............ $N=51$, $r_{sw}=0.770 \pm 0.038$
For females........... $N=43$, $r_{sw}=0.864 \pm 0.026$
For both sexes........ $N=94$, $r_{sw}=0.821 \pm 0.023$

For comparison with those we have the constants based on 1000 male and 1000 female full-term new-born infants from the Lambeth Lying-in Hospital by Pearson [34]. The results are:

For males............ $N=1000$, $r_{sw}=0.644 \pm 0.012$
For females........... $N=1000$, $r_{sw}=0.622 \pm 0.013$

Reducing the Anthropometric Committee's [35] data, which as noted by Pearson are somewhat heterogeneous in origin, we find:

For males............ $N=451$, $r_{sw}=0.665 \pm 0.018$
For females........... $N=466$, $r_{sw}=0.539 \pm 0.022$

The correlations between length and weight in Dr. Rood Taylor's series are:

For males .... $r_{sw}=0.668 \pm 0.034$
For females....................... $r_{sw}=0.749 \pm 0.027$

For both males and females our correlations are higher than those found by others. The differences are:

	Pearson's series.	*British Association.*	*Taylor's series.*
For males,	$+0.126 \pm 0.040$	$+0.105 \pm 0.042$	$+0.102 \pm 0.051$
For females,	$+0.242 \pm 0.029$	$+0.325 \pm 0.034$	$+0.115 \pm 0.037$

[34] Pearson, Proc. Roy. Soc. Lond., 1899, **66**, p. 25.
[35] British Association Report (Southport), 1883, p. 286.

In most cases the differences are apparently statistically significant in comparison with their probable errors. Thus our series of infants, both male and female, are certainly more highly correlated in their weight and length than the series studied by others.

Summarizing the results of this brief and superficial comparison, it appears that while our series differ in correlation, they may nevertheless be considered to show a very satisfactory *general* agreement in both mean, and variability with babies studied by others. Considering the possible influence of race, age, and social status, the agreement seems rather remarkable.

We assert, therefore, that we are dealing with the constants of "normal" male and female infants, not merely because they are apparently normal from the comparative standpoint of the obstetrician, but because they give statistical constants in fair agreement with those for babies studied by others.

We now turn to the constants for adults. Since these are fundamental to the determination of many of the relationships in subsequent sections, we shall give them for each of the various subseries. The constants for stature appear in table 8, those for body-weight in table 11.

TABLE 8.—*Statistical constants for stature in adults of Nutrition Laboratory series.*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Men.				
Original series:				
Athletes	16	177.44±1.57	9.33±1.11	5.26±0.63
Others	62	171.82±0.58	6.79±0.41	3.95±0.24
Whole series	89	172.45±0.56	7.80±0.39	4.53±0.23
Gephart and Du Bois selection	72	172.75±0.56	6.98±0.39	4.04±0.23
First supplementary series	28	174.61±1.04	8.17±0.74	4.68±0.42
Original and first supplementary series	117	172.97±0.50	7.94±0.35	4.59±0.20
Second supplementary series	19	172.95±0.75	4.83±0.53	2.79±0.31
Other than Gephart and Du Bois selection	64	173.20±0.69	8.21±0.49	4.74±0.28
All men of three series	136	172.96±0.44	7.59±0.31	4.39±0.18
Women.				
Original series	68	161.87±0.43	5.29±0.31	3.27±0.19
Supplementary series	35	162.14±0.57	4.99±0.40	3.08±0.25
Both series	103	161.96±0.34	5.19±0.24	3.20±0.15

If the criterion of the suitability of our series of individuals were mean stature only, we should be embarrassed by the wealth of available materials for comparison. Stature is one of the more conspicuous and more generally interesting characteristics of races or of the populations of different geographic divisions. The number of average statures available is therefore very large. But our comparison involves not merely the average value, but the distribution of the statures around the average. Hence we must base our comparisons on series which have full data for the determination of variability as well as of type.

For comparison, we have the constants for the stature of 1,000 students 18 to 25 years of age, measured in the Harvard gymnasium and published by Castle,[36] and for 25,878 American recruits calculated by Pearson.[37] Turning to the English, we have Schuster's[38] values for Oxford students aged 18 to 23 or more years, Pearson's[39] and Macdonell's[40] constants for Cambridge undergraduates and for Macdonell's[41] Scottish students. Turning to data other than that for students, Pearson[42] has given a series of constants drawn from his family records and Pearson and Lee[43] have supplied those for first and second generations of British families.

TABLE 9.—*Statistical constants for stature in men and women in general.*

Series.	Men. Mean.	Men. Standard deviation.	Men. Coefficient of variation.	Women. Mean.	Women. Standard deviation.	Women. Coefficient of variation.
American:						
Harvard students	175.34	6.58	3.76	......	....	....
Army recruits	170.94	6.56	3.84	......	....	....
English:						
Oxford students	176.50	6.61	3.74	......	....	....
Cambridge students, Pearson	174.91	6.41	3.66	162.26	6.00	3.70
Cambridge students, MacDonell	174.88	6.46	3.70	......	....	....
Pearson's second generation	174.37	6.88	3.95	162.23	6.63	4.09
Pearson's family records	172.81	7.04	4.07	159.90	6.44	4.03
Pearson's parental generation	171.91	6.86	3.99	158.70	6.07	3.83
New South Wales criminals	169.87	6.58	3.87	158.09	6.15	3.89
Scottish students	171.70	5.94	3.46	......	....	....
MacDonell's convicts	166.46	6.45	3.88	......	....	....
Goring's convicts	166.29	6.76	4.06	......	....	....
Swedes	169.79	6.81	4.01	158.71	6.72	4.23
Hessians	167.36	7.19	4.30	156.18	6.90	4.40
French	166.80	6.47	3.88	156.10	6.79	4.35
Bavarians, Pearl	166.55	6.39	3.84	154.71	6.21	4.02
Bavarians, Pearson	165.93	6.68	4.02	163.85	6.55	4.26

While it is now known that, in England at least, certain classes of criminals are differentiated from the general population, it is interesting to compare the constants for 3000 *non-habitual* male criminals[44] measured at Scotland Yard and analyzed by Macdonell,[45] the constants for 3000 men studied by Goring[46] in his masterly treatment of the British

[36] Castle, Heredity and Eugenics, Cambridge, 1916, p. 61.
[37] Pearson, The Chances of Death, 1897, **1**, p. 276.
[38] Schuster, Biometrika, 1911, **8**, p. 49.
[39] Pearson, Proc. Roy. Soc. Lond., 1899, **66**, p. 26.
[40] Macdonell, Biometrika, 1901, **1**, p. 191.
[41] Macdonell, Proc. Anat. and Anthrop. Soc. Univ. Aberdeen (*fide* K. Pearson, Biometrika, 1911, **8**, p. 49).
[42] Pearson, The Chances of Death, 1897, **1**, p. 294.
[43] Pearson and Lee, Biometrika, 1901, **2**, p. 370.
[44] The majority of the prisoners were English and Welsh, many were Irish, and only a few Scotch. None were foreigners. All were over 21 years of age.
[45] Macdonell, Biometrika, 1901, **1**, p. 191.
[46] Goring, The English Convict., Lond., 1913, pp. 178–179.

criminal, and for a large series of New South Wales criminals for which we are indebted to Powys.[47]

For races other than Anglo-American we have Pearson's[48] Bavarian and French men and women and Pearl's[49] constants for Swedes, Hessians and Bavarians.

The means, standard deviations and coefficients of variation of these various series are assembled in table 9.

Comparison of the constants for stature of our total men and total women with these various series is facilitated by the differences in table 10. These are taken so that a positive sign indicates higher mean or variability in the Nutrition Laboratory series.

TABLE 10.—*Comparison of statistical constants for stature in Nutrition Laboratory series with the values for men and women in general.*

Series.	Men.			Women.		
	Mean.	Standard deviation.	Coefficient of variation.	Mean.	Standard deviation.	Coefficient of variation.
American:						
Harvard students	−2.38	+1.01	+0.63	......	....	....
Army recruits	+2.02	+1.03	+0.55	......	....	....
English:						
Oxford students	−3.54	+0.98	+0.65	......	....	....
Cambridge students, Pearson	−1.95	+1.18	+0.73	−0.30	−0.81	−0.50
Cambridge students, MacDonell	−1.92	+1.13	+0.69	......	....	....
Pearson's second generation	−1.41	+0.71	+0.44	−0.27	−1.44	−0.89
Pearson's family records	+0.15	+0.55	+0.32	+2.06	−1.25	−0.83
Pearson's parental generation	+1.05	+0.73	+0.40	+3.26	−0.88	−0.63
New South Wales criminals	+3.09	+1.01	+0.52	+3.87	−0.96	−0.69
Scottish students	+1.26	+1.65	+0.93	......	....	....
MacDonell's convicts	+6.50	+1.14	+0.51	......	....	....
Goring's convicts	+6.67	+0.83	+0.33	......	....	....
Swedes	+3.17	+0.78	+0.38	+3.25	−1.53	−1.03
Hessians	+5.60	+0.40	+0.09	+5.78	−1.71	−1.20
French	+6.16	+1.12	+0.51	+5.86	−1.60	−1.15
Bavarians, Pearl	+6.41	+1.20	+0.55	+7.25	−1.02	−0.82
Bavarians, Pearson	+7.03	+0.91	+0.37	−1.89	−1.36	−1.06

As far as average stature is concerned, our series show a superiority practically throughout. Only the Oxford, Cambridge, and Harvard men, Cambridge women, Pearson's filial generation measurements for both men and women, and Pearson's Bavarian women are taller than the subjects included in our normal series.

Now comparison of average statures involves very great difficulties. In none of these series is there a correction for the slight premaximum increase or the postmaximum decrease occurring in the age period ordinarily designated as adult life. This is probably a matter of negli-

[47] Powys, Biometrika, 1901, **1**, p. 44.
[48] Pearson, The Chances of Death, 1897, **1**, p. 295.
[49] Pearl, Biometrika, 1905, **4**, p. 13.

gible importance. A far greater difficulty is inherent in the factor of racial differentiation. One has only to glance at such tables as those of Martin[50] or the discussion and maps of Ripley[51] to realize how great the racial, geographical, and social factors are in determining the average stature of a group of individuals. The fact that our normal men and women are taller than those with which we have compared them may be due to one or more of three factors.

a. A differentiation of the American population from the European with respect to stature.

b. An indirect selection of the taller men and women from the general American population due to the individuals volunteering for these metabolism observations being a superior class.[52]

c. Unconscious selection of taller individuals for metabolism measurements by those who have had to choose among the subjects who presented themselves.

Some evidence on the first of these questions is afforded by abstracting from Martin's *Anthropologie* the average statures, as far as given in the comparative table (p. 213–217).

	Men.	*Women.*
French	164.1	157.0
Bavarians	165.6	.....
Swedes	170.9	.....
American whites	171.9	.....
English	172.8	159.9

Even if we increase the stature of the French and Bavarian men by 1 cm. to correct for the age at which measurements were made for military purposes, we note that the American white population stands next to that of the middle classes of Great Britian in stature.

Fortunately we may take from Baxter's[53] report the average statures of immigrants of various nationalities. As abstracted by the Anthropometric Committee of the British Association[54] they are as follows:

	Centimeters.		*Centimeters.*		*Centimeters.*
Norwegians	171.9	English	169.2	French	168.3
Canadians, chiefly French	170.3	Hungarians	169.2	Poles	168.2
Swedes	170.0	Germans	169.1	Italians	167.7
Danes	169.4	Swiss	168.7	Spaniards	166.8
Dutch	169.3	Russians	168.7	Portuguese	166.3

[50] Martin, Lehrbuch der Anthropologie, 1914. See especially pp. 204–237.

[51] Ripley, The Races of Europe, 1900. See especially pp. 78–102.

[52] How great the influence of social differentiation may be is well shown by a comparison of the regression slopes for fraudulent criminals and for criminals at large, in Goring's *English Convict*. It is also clear from the Swiss data for stature by occupation given on page 90 of Ripley's *Races of Europe*.

[53] Baxter, Statistics, Medical and Anthropological, 1875.

[54] British Association Report (Southport), 1883, pp. 269–271. See also W. H. Holmes, Am. Journ. Phys. Anthrop., 1918, **1**, p. 84.

Thus racial differentiation between European and American population is ample to account for the observed differences in our mean statures. Our men are intermediate between the general population and a highly selected group like Harvard University students.[55]

In regard to variability, our men are more variable and our women are less variable throughout than those studied by others for purely anthropometric purposes.

Since the average stature for Americans seems to be higher than that of most of the European groups with which they are compared, the absolute variability would be expected to be greater in Americans; but the relationships noted hold whether variability be measured in centimeters by the standard deviation or in percentages of the total stature by the coefficient of variation.

TABLE 11.—*Statistical constants for body weight in adults.*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Men.				
Original series:				
Athletes	16	73.82±2.17	12.87±1.53	17.43±2.14
Others	62	63.03±0.77	9.02±0.55	14.32±0.88
Whole series	89	64.33±0.77	10.73±0.54	16.68±0.87
Gephart and Du Bois selection	72	63.33±0.67	8.37±0.47	13.22±0.76
First supplementary series	28	62.69±1.34	10.48±0.94	16.72±1.55
Original and first supplementary series	117	63.94±0.67	10.69±0.47	16.73±0.76
Second supplementary series	19	65.06±1.13	7.30±0.80	11.22±1.24
Other than Gephart and Du Bois selection	64	64.96±1.02	12.04±0.72	18.54±1.14
All men of three series	136	64.10±0.60	10.30±0.42	16.06±0.67
Women.				
Original series	68	54.49±0.88	10.78±0.62	19.78±1.19
Supplementary series	35	60.36±1.35	11.84±0.95	19.61±1.64
Both series	103	56.48±0.76	11.49±0.54	20.35±1.00

Now, admitting freely that many of these differences are statistically significant, we nevertheless feel that one can hardly examine these constants collected by various writers in anthropometric investigations, with no physiological purpose whatever in view, in comparison with our own without being impressed by the general suitability of our materials as a basis for generalizations applicable to large populations. Our averages seem to be roughly representative of the *American* population. Our men are somewhat more variable than we would like, but our women are distinctly less variable than women in general. It is clear, therefore, that our series of individuals is characterized not merely by an average stature comparable with that of men in general, but that it exhibits (at least in the males) a variability of stature which is (roughly speaking) typical of the population at large. This "lack of uniformity" or "lack of homogeneity" in the series of

[55] The average stature of 327 Amherst College students (of average age 21.5 years) is 172.9 cm. Anthropometric Committee's Report Brit. Ass. Rept. (Southport), 1883, p. 260.

men and women dealt with is one of its chief merits. If laboratory studies of basal metabolism are to have a broad application in medical and social science they should be made upon series *representative of the population at large.* It is only under these conditions that generalizations of wide usefulness can be safely made.

Our constants for body-weight, *taken without clothing,* in the various series are given in table 11.

For comparison with our own series of body-weights we are fortunate in having the table of weight *taken without clothing* of 1,000 Harvard men aged 18 to 25 years published by Professor Castle,[56] that for Oxford undergraduates, weighed with clothing but without boots, given by Schuster,[57] the values for 1,000 Cambridge men and 160 Cambridge women given by Pearson,[58] and Pearson's [59] reduction of Francis Galton's series of body-weights, taken with ordinary indoor clothing, for British men ($N=520$) and women ($N=276$). Goring has given a most valuable series from British prisons,[60] measured in shirt and trousers only. For Germans (Bavarians) Pearson [61] has determined constants for the 535 men and 340 women measured by Bischoff.

The results, uncorrected for weight of clothing, are as follows:

	Mean.	*S. D.*	*C. V.*
Castle's Harvard men	65.66	7.84	11.94
Schuster's Oxford men	68.91	7.45	10.80
Pearson's Cambridge men	69.30	7.51	10·83
Pearson's Cambridge women	56.97	6.36	11.17
Galton's British men	64.86	4.54	10.37
Galton's British women	55.34	4.60	13.37
Goring's convicts	64.45	7.80	12.09
Pearson's Bavarian men	50.17	10.38	20.67
Pearson's Bavarian women	41.92	10.51	25.07

Unfortunately the number of series of body-weight measurements available for comparison is small. Furthermore body-weight is a much more variable character than stature. One must, therefore, expect greater actual differences between series of observations made at different times and places. How large the differences may be is shown by the great discrepancy between the British and the Bavarians. Our data show constants of roughly the same order of magnitude as those available for comparison.

In turning to the problem of the closeness of correlation in the stature and weight of the subjects examined as a criterion of their "normality" as compared with men at large, it will be important to

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[56] Castle, Heredity and Eugenics, Cambridge, 1916, p. 61.
[57] Schuster, Biometrika, 1911, **8**, p. 49.
[58] Pearson, Proc. Roy. Soc. Lond., 1899, **66**, p. 26.
[59] Pearson, The Chances of Death, **1**: 305, 1897. Constants slightly erroneous.
[60] Goring, The English Convict, 1913, pp. 178–179.
[61] Pearson, The Chances of Death, **1**: 305, 1897. We can offer no explanation for the great variation in the German series.

remember that in selecting our series for comparison we must choose those of adult age in order to eliminate the influence of growth. Some of the best studies on the correlation between stature and weight—for example, those of Boas [62] and of Boas and Wissler [63] on Toronto and Worcester children, as well as the more recent investigation of Elderton [64] on the stature and weight of Glasgow school children, carried somewhat farther by Isserlis,[65] are therefore not available for our present purposes.

The correlations between stature and weight in our adults are given in table 12.

TABLE 12.—*Correlation between weight and stature and partial correlation between weight and stature for constant age in the several series.*

Series.	N	Correlation r_{ws}	$\frac{r_{ws}}{E_{r_{ws}}}$	Partial correlation $_ar_{ws}$	$\frac{_ar_{ws}}{E_{_ar_{ws}}}$	Difference $r_{ws}-{_ar_{ws}}$
Men.						
Original series:						
Athletes	16	0.6943±0.0873	7.95	0.6361±0.1004	6.34	+0.0582
Others	62	0.4010±0.0719	5.58	0.3999±0.0720	5.55	+0.0011
Whole series	89	0.5320±0.0513	10.37	0.5376±0.0508	10.58	−0.0056
Gephart and Du Bois selection	72	0.6654±0.0443	15.02	0.6773±0.0431	15.71	−0.0119
First supplementary series	28	0.7461±0.0565	13.21	0.7468±0.0564	13.24	−0.0007
Original and first supplementary series	117	0.5712±0.0420	13.60	0.5783±0.0415	13.93	−0.0071
Second supplementary series	19	0.6031±0.0984	6.13	0.5960±0.0998	5.97	+0.0071
Other than Gephart and Du Bois selection	64	0.5149±0.0620	8.31	0.5362±0.0601	8.92	−0.0213
All men of three series	136	0.5725±0.0389	14.72	0.5772±0.0386	14.95	−0.0047
Women.						
Original series	68	0.2191±0.0779	2.81	0.2205±0.0778	2.83	−0.0014
Supplementary series	35	0.5386±0.0809	6.66	0.4969±0.0859	5.78	+0.0417
Both series	103	0.3257±0.0594	5.48	0.2995±0.0605	4.95	+0.0262

The partial correlations in which the influence of age is eliminated have been computed from the formula

$$_ar_{ws}=\frac{r_{ws}-r_{aw}r_{as}}{\sqrt{1-r_{aw}^2}\sqrt{1-r_{as}^2}}$$

and placed beside the others for comparison.

It is to be noted that correction for the influence of age has modified the values of the constants very little indeed. They have sometimes been slightly raised and sometimes slightly lowered by correction for this factor. Age differences in the series can not, therefore, account for any of the observed differences in correlation.

[62] Boas, Rept. U. S. Comm. Educ., 1896–97, p. 1541.
[63] Boas and Wissler, Rept. U. S. Comm. Educ., 1904, p. 26.
[64] Elderton, Biometrika, 1914, **10**, p. 288.
[65] Isserlis, Biometrika, 1915, **11**, p. 50.

The results in table 12 seem very reasonable and consistent with one exception. The original published series of women seems abnormally low in comparison with the second series and with men. The relationships for the original series and the supplementary series are shown in diagrams 2 and 3.

The straight lines in these diagrams represent the equations:

For original series.................. $w = -17.83 + 0.45s$
For supplementary series.......... $w = -146.68 + 1.28s$

Clearly the rate of increase in weight per centimeter of length is much greater in the supplementary series.

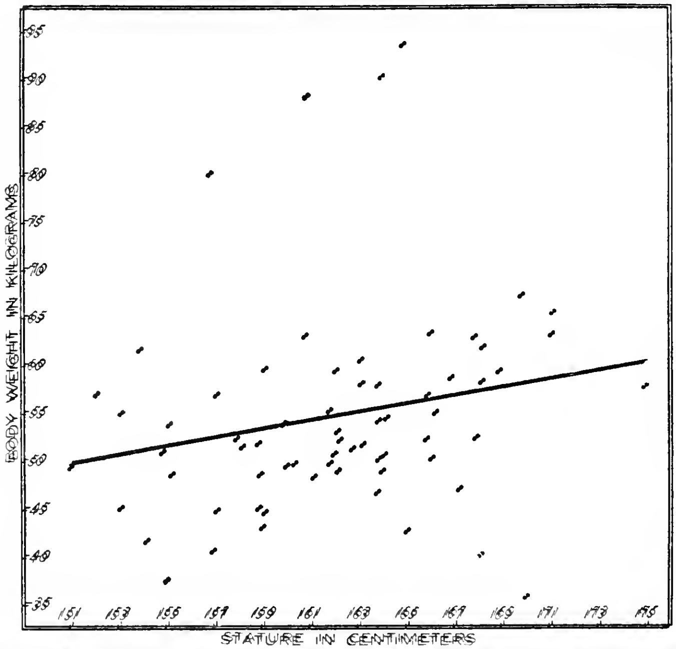

DIAGRAM 2.—Relationship between stature and weight in original series of women. See text for discussion of four aberrant individuals in upper part of field.

In the original series one notes four individuals towards the upper part of the field who are very heavy in relation to their stature. These are Miss O. A., Dr. M. D., Miss H. H., and Miss H. D. If these be removed the variability in body-weight is greatly reduced, *i.e.*, from 10.78 to 6.87. The correlation is raised from $r = 0.219$ to $r = 0.340$, but this constant is still considerably lower than that in the supplementary series.

Apparently the observations are fairly well grouped around the straight lines and we must simply admit that, in gathering small samples of data, two groups were secured which differed sensibly in the degree of correlation of their bodily characters.

The relationship between stature and body-weight in the total male ($N=136$) and the total female ($N=103$) series may now be represented in a different way.

The straight-line equation connecting weight and stature in the total series are:

For men............ $w=-70.303+0.777s$
For women.......... $w=-60.332+0.721s$

These are represented on the same scale for the two sexes on diagram 4. The "mean body-weight" has been calculated for each grade of stature. With less than 150 individuals available for each sex the "averages" sometimes represent a single individual merely and are extremely irregular. The straight line serves fairly well to smooth them.

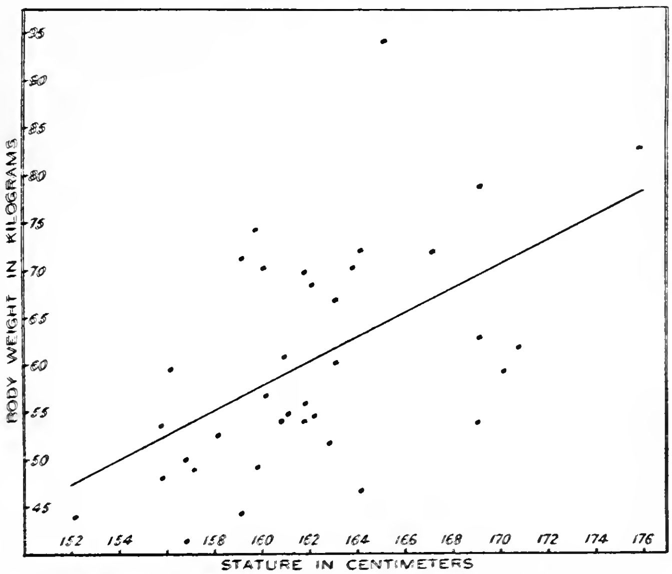

DIAGRAM 3.—Relationship between stature and body weight in supplementary series of women. See diagram 2 and text.

The diagram brings out clearly a point noted above, namely the unfortunate narrowness in the range of variation of stature in our series of women.

For comparison we have several series of data. First of all may be mentioned Castle's[66] 1000 Harvard men—gymnasium records without clothing—which give:

$$r=0.704\pm0.015$$

Pearson,[67] working with measurements of 1000 male and 160 female Cambridge students, found:

For men............ $r=0.486\pm0.016$
For women.......... $r=0.721\pm0.026$

[66] Castle, Heredity and Eugenics, Cambridge, 1916, p. 61.
[67] Pearson, Proc. Roy. Soc. Lond., 1899, 66, p. 26.

For Oxford men, E. Schuster[68] found the following correlations between height and weight, the latter unfortunately taken with the clothing except the boots:

Age 18, $N=129$,	$r=0.50\pm0.04$
Age 19, $N=330$,	$r=0.63\pm0.02$
Age 20, $N=209$,	$r=0.68\pm0.03$
Age 21, $N=137$,	$r=0.76\pm0.02$
Age 22, $N=$ 95,	$r=0.72\pm0.03$

General average...0.66

For stature and body-weight in 2502 British convicts, weighed in trousers and shirt only, Goring[69] finds:

$$r_{ws}=0.555\pm0.009$$

Again for height and weight in 500 male criminals examined by Goring, the correlations deduced by Whiting[70] are:

For stature and weight...................... $r_{sw}=0.580\pm0.020$
For stature and weight with age constant.... $_ar_{sw}=0.583\pm0.020$

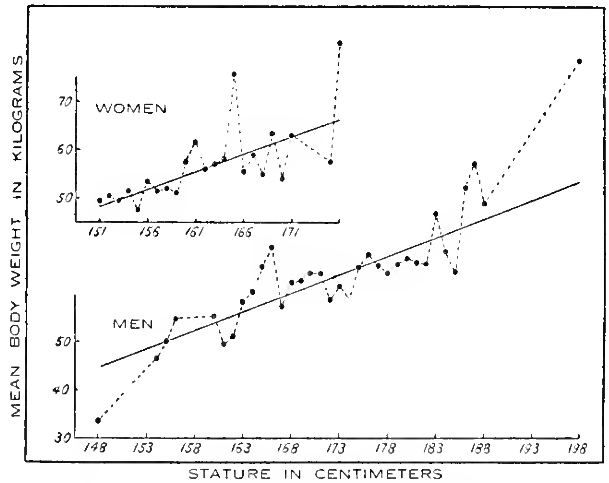

DIAGRAM 4.—Variation in mean body-weight of men and women with stature.

Our correlations for men are, roughly speaking, of the same order of magnitude as those which have been published by others. Unfortunately, only Pearson's small series of women, but slightly larger than our own, is available for comparison. The agreement here is not good. Only further work on the relationship between stature and body-weight in women will answer the question of the degree of correlation to be expected between these two physical characters.

[68] Schuster, Biometrika, 1911, 8, p. 51.
[69] Goring, The English Convict, Lond., 1913, p. 389.
[70] Whiting, Biometrika, 1915, 11, p. 8.

The materials for adults may be tested for normality, in the general sense in which we have used the term here, in two other ways.

Age and stature, in adult life, should not be sensibly correlated except as a result of post-maximum shrinkage. Our data cover a portion of the age of pre-maximum increase and of post-maximum decrease as well as the age of maximum stature. Our correlations are given in table 13. Some of the constants are positive while some are negative. In only the athletes are the coefficients as much as 2.5 times as large as their probable errors. When N is small the ordinary standards of trustworthiness can no longer be maintained. Taking the results as a whole, we have no reason to conclude that in the age range covered by our data there is any great change in stature with age.

TABLE 13.—*Correlation between age and stature and age and weight and partial correlation between age and weight for constant stature.*

Series.	N	Correlation between age and stature r_{as}	$\frac{r_{as}}{E_{r_{as}}}$	Correlation between age and weight r_{aw}	$\frac{r_{aw}}{E_{r_{aw}}}$	Partial correlation ${}_sr_{aw}$	$\frac{{}_sr_{aw}}{E_{{}_sr_{aw}}}$
Men.							
Original series:							
Athletes	16	-0.4346 ± 0.1368	3.18	-0.3763 ± 0.1447	2.60	-0.1150 ± 0.1664	0.69
Others	62	$+0.0687 \pm 0.0853$	0.81	$+0.3037 \pm 0.0778$	3.90	$+0.3022 \pm 0.0778$	3.88
Whole series	89	-0.1651 ± 0.0696	2.37	-0.0106 ± 0.0715	0.15	$+0.0925 \pm 0.0709$	1.30
Gephart and Du Bois selection	72	$+0.0283 \pm 0.0794$	0.36	-0.1476 ± 0.0778	1.90	-0.2230 ± 0.0755	2.95
First supplementary series	28	$+0.0641 \pm 0.1269$	0.51	$+0.1565 \pm 0.1243$	1.26	$+0.1636 \pm 0.1241$	1.32
Original and first supplementary series	117	-0.1230 ± 0.0614	2.00	$+0.0209 \pm 0.0623$	0.34	$+0.1120 \pm 0.0616$	1.82
Second supplementary series	19	-0.1594 ± 0.1508	1.06	-0.1185 ± 0.1526	0.78	-0.0284 ± 0.1546	0.18
Other than Gephart and Du Bois selection	64	-0.1972 ± 0.0810	2.43	$+0.0515 \pm 0.0841$	0.61	$+0.1820 \pm 0.0815$	2.23
All men of three series	136	-0.1154 ± 0.0571	2.02	$+0.0067 \pm 0.0578$	0.12	$+0.0893 \pm 0.0574$	1.56
Women.							
Original series	68	$+0.0921 \pm 0.0811$	1.14	-0.0050 ± 0.0818	0.06	-0.0259 ± 0.0817	0.32
Supplementary series	35	$+0.2395 \pm 0.1075$	2.23	$+0.4422 \pm 0.0917$	4.82	$+0.3828 \pm 0.0973$	3.93
Both series	103	$+0.1462 \pm 0.0650$	2.25	$+0.2867 \pm 0.0610$	4.70	$+0.2557 \pm 0.0621$	4.12

For comparison with our own constants we have those for 500 criminals examined by Goring. The correlations deduced by Whiting[71] are:

For age and stature .... $r_{as} = +0.023 \pm 0.030$
For age and stature with weight constant .... ${}_wr_{as} = -0.070 \pm 0.030$

General observation suggests that individuals tend to gain in weight with increasing age,[72] even after the normal period of growth has passed. In support of such general observation may be cited the

[71] Whiting, Biometrika, 1915, **11**, p. 8.
[72] It seems quite possible that the correlation between weight and heat-production may be somewhat disturbed by the correlation of weight with age. It is, therefore, necessary to investigate such relationships as this in detail.

constants obtained by Whiting[73] for age and weight in 500 criminals examined by Goring. The correlations deduced are:

For age and weight.............................. $r_{aw} = +0.136 \pm 0.030$
For age and weight with stature constant........ ${}_sr_{aw} = +0.151 \pm 0.030$

These constants indicate a slight increase in weight with increasing age.

Our own materials show the correlations given in table 13. Since the problem of any actual gain in weight after the completion of growth involves a consideration of the stature of the individuals, the correlations for age and weight have been corrected for the influence of stature by the use of the formula

$$ {}_sr_{aw} = \frac{r_{aw} - r_{sa}r_{sw}}{\sqrt{1-r_{sa}^2}\sqrt{1-r_{sw}^2}} $$

Among the men only the correlation for the 62 "other men" of the original series can be looked upon as statistically significant.

The partial correlations between age and weight for constant stature are positive in all the larger series of men, excepting only the Gephart and Du Bois selection,[74] and indicate a slight tendency for increase in body-weight with age in men.

The women of the first series show practically no correlation between age and body-weight. Correction for the possible influence of stature does not materially alter the relationship. The supplementary series, however, shows material and statistically significant positive correlation, indicating decided increase of weight with age. The correlation is not so large, but nevertheless apparently statistically significant, for the total available women. The values of the gross correlations are but slightly reduced when correction is made for the influence of stature by the use of the partial correlation formula. The constants for the second series of women and for the entire series of women seem to suggest that women have a greater tendency than men to increase in weight with age. The apparent contradiction between the results of the first and of the supplementary series is perhaps due to differences in age. The individuals of the second series are on the average about 13 years older than those of the first. Thus the average age in the first series is 26.7 years, whereas that of the second series is 39.9 years, and that of all the women is 31.1 years. The first series shows a standard deviation of only 9.9 years around the average age of 26.7 years, whereas the second series shows a standard deviation of 16.0 years around the average age of 39.9 years, and the whole series shows a variation of 13.8 years around the average of 31.1 years.

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[73] Whiting, Biometrika, 1915, 11, p. 8.

[74] The negative correlation and the negative partial correlation for constant stature found in the Gephart and Du Bois selection are perhaps due to the arbitrary removal of individuals which do not conform to a preconceived standard.

Higher correlation between age and weight in a group of women averaging 40 years in age than in a group averaging 27 years of age is in accord with the rather general belief that after the climacteric women tend to gain in weight.

The variation constants for body-surface measured by the Du Bois height-weight chart appear in table 14.

TABLE 14.—*Statistical constants for body-surface in adults as estimated by Du Bois height-weight chart*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Men.				
Original series:				
Athletes	16	1.904±0.0326	0.1933±0.0230	10.15±1.22
Others	62	1.742±0.0113	0.1315±0.0080	7.55±0.46
Whole series	89	1.760±0.0114	0.1593±0.0081	9.05±0.46
Gephart and Du Bois selection	72	1.753±0.0108	0.1360±0.0076	7.76±0.44
First supplementary series	28	1.759±0.0228	0.1785±0.0161	10.15±0.92
Original and first supplementary series	117	1.760±0.0102	0.1631±0.0072	9.26±0.41
Second supplementary series	19	1.775±0.0168	0.1089±0.0119	6.14±0.67
Other than Gephart and Du Bois selection	64	1.773±0.0149	0.1765±0.0105	9.96±0.60
All men of three series	136	1.762±0.0091	0.1567±0.0064	8.89±0.37
Women.				
Original series	68	1.566±0.0113	0.1378±0.0080	8.80±0.51
Supplementary series	35	1.637±0.0180	0.1577±0.0127	9.63±0.78
Both series	103	1.590±0.0099	0.1485±0.0070	9.34±0.44

For this character we have no comparable data from other sources. The constants are, therefore, of primary importance in their relation to the further calculation necessary for the discussion of subsequent sections. The average body-surface is about 1.8 square meters in men and about 1.6 square meters in women. The variability of the superficial area of the body is about 9 per cent of this amount in both sexes. The coefficients of variation occupy an intermediate position between those for stature and those for body-weight, as shown in the final columns of tables 8 and 11, in every series.

The constants for pulse-rate are set forth in table 15. The only comparable data of which we are aware are those of Körösy and Goring for conscripts and convicted men. For pulse-rate in 500 convicts examined by Goring the constants determined by Whiting [75] and the difference from our own for men are:

1	2 *Our whole series.*	3 *Whiting's whole series.*	4 *Difference between 2 and 3.*	5 *Whiting's weak-minded.*	6 *Difference between 2 and 5.*
Mean.	61.26±0.41	74.22±0.25	12.96±0.48	77.62±0.58	16.36±0.71
S. D.	6.73±0.29	11.06±0.17	4.33±0.34	11.85±0.41	5.12±0.50
C. V.	10.99±0.48	14.89±0.24	3.90±0.54	15.27±0.54	4.28±0.72

These values are far larger than ours, in mean, absolute variability, and relative variability. This is clearly due to the facts (*a*) that they

[75] Whiting, Biometrika, 1915, **11**, pp. 1–37.

are made upon a series of individuals from which physically and mentally abnormal men were not excluded, and (*b*) that the rates were taken with the convict sitting in his cell, writing, reading, or doing nothing *about 15 minutes after early dinner* instead of 12 hours after the last meal and in a state of complete muscular repose.

TABLE 15.—*Statistical constants for pulse-rate in adults.*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Men.				
Original series:				
Athletes	16	62.00±1.01	5.98±0.71	9.64±1.16
Others	62	60.81±0.54	6.29±0.38	10.34±0.63
Whole series	88	60.92±0.47	6.48±0.33	10.64±0.55
Gephart and Du Bois selection	71	61.27±0.51	6.43±0.36	10.49±0.60
First supplementary series	28	62.54±0.87	6.81±0.61	10.89±0.99
Original and first supplementary series	116	61.31±0.41	6.60±0.29	10.77±0.48
Other than Gephart and Du Bois selection	50	61.26±0.68	7.14±0.48	11.65±0.80
All men of three series	121	61.26±0.41	6.73±0.29	10.99±0.48
Women.				
Original series	68	69.12±0.67	8.18±0.47	11.83±0.69
Supplementary series	22	67.27±1.18	8.20±0.83	12.19±1.26
Both series	90	68.67±0.59	8.25±0.41	12.01±0.61

Körösy's data for conscripts[76] are physiologically more nearly comparable with our own. They were taken on a group from which all individuals not having a perfectly healthy heart had been excluded. The countings were made in the early morning soon after the men were wakened and while they were still in a position of rest. The constants deduced by Bell[77] are compared with our own as follows:

	Körösy's series.	*Our series.*	*Difference.*
Mean	64.21±2.71	61.26±0.41	2.95±2.74
S. D.	8.49±0.36	6.73±0.29	1.76±0.46
C. V.	13.22±0.40	10.99±0.48	2.23±0.62

These results are in much closer agreement with our own than the determinations on convicts; but means, absolute variabilities, and relative variabilities are larger than in our series.

Since pulse-rate is a physiological measure well known to be affected by other physiological factors, we take these facts to indicate that our records for pulse-rate—and in consequence those for metabolism as well, for both were measured simultaneously—have been determined under conditions which introduced the minimum external influence.

Turning to a more detailed examination of our own constants, we note that the women have a more rapid and more variable pulse than the men. The averages are:

[76] Körösy, Deutsch. Archiv. f. klin. Med., 1910, p. 267.
[77] Bell, Biometrika, 1911, 8, p. 232.

	For original Nutrition Laboratory series.		*For all available data.*
For 89 men.........	60.92±0.47	For all men..........N=121	61.26±0.41
For 68 women......	69.12±0.67	For all women........N= 90	68.67±0.59
	+8.20±0.82		+7.41±0.72

In both comparisons the women show from 7 to 8 beats per minute more than the men, and these differences are about 10 times as large as the probable errors of their determination. The sexual differentiation thus indicated has been noted by other writers. Thus Leonard Hill,[78] in an article on "The mechanism of the circulation of the blood" says:

"The pulse frequency is greater in women than in men, but this difference almost disappears if men and women of equal stature are compared."

Langendorff, in his article on the circulation of the blood,[79] states that the pulse of adult men resting in bed is about 60, while standing it is 70 to 75 per minute, and that in women it is somewhat higher. Professor Robert Tigerstedt[80] states that in all ages, from 2 years on, the pulse-rate of the woman is higher than that of the man. The smaller size of the woman plays a rôle, but even if individuals of the same stature are compared the difference is persistent though smaller.

We now turn to the constants for total heat-production.

TABLE 16.—*Statistical constants for total heat-production per 24 hours in adults.*

Series.	N	Average.	Standard deviation.	Coefficient of variation.
Men.				
Original series:				
Athletes..........................	16	1876.56±41.33	245.13±29.23	13.06±1.58
Others..........................	62	1607.97±12.20	142.38± 8.62	8.85±0.54
Whole series....................	89	1638.36±14.64	204.82±10.36	12.50±0.64
Gephart and Du Bois selection.....	72	1623.46±14.11	177.55± 9.98	10.94±0.62
First supplementary series...........	28	1605.18±28.19	221.14±19.93	13.78±1.27
Original and first supplementary series	117	1630.42±13.05	209.32± 9.23	12.84±0.58
Second supplementary series.........	19	1639.84±26.77	172.99±18.93	10.55±1.17
Other than Gephart and Du Bois selection..........................	64	1641.05±19.48	231.04±13.77	14.08±0.86
All men of three series..............	136	1631.74±11.84	204.66± 8.37	12.54±0.52
Women.				
Original series......................	68	1354.69±12.25	149.74± 8.66	11.05±0.65
Supplementary series................	35	1338.51±18.78	164.72±13.28	12.31±1.01
Both series..........................	103	1349.19±10.31	155.18± 7.29	11.50±0.55

The means, standard deviations and coefficients of variation for total heat-production in calories per 24 hours are given in table 16. The entries in this table, representing as they do the constants for the most extensive series of data available on basal metabolism in men and women, have a great deal of interest. The first column shows

[78] Hill, Schäfer's Text-Book of Physiology, London and New York, 1900, **2**, p. 101.

[79] Langendorff, Zuntz and Loewy's Lehrbuch der Physiologie des Menschen, Leipzig, 1913, 2, Aufl., p. 373.

[80] Tigerstedt, Lehrbuch der Physiologie des Menschen, Leipzig, 1913, 7, Aufl., **1**, p. 282.

that the average basal metabolism of normal men is measured by a daily heat-production of about 1600 to 1650 calories. All the series, even those in which the number of individuals is very small, are reasonably consistent except for the athletes, which show an unusually high metabolism. Women show an average daily heat-production, when in complete muscular repose and in the post-absorptive state, of about 300 calories per day less than men. The average daily basal heat-production of new-born infants is, as shown in table 5, about 140 to 145 calories. This is about 10 per cent of that of adult women. In examining these values one must, however, remember that they are uncorrected for the influence of stature, body-weight, or age, all of which have important rôles as proximate factors in the determination of the basal daily heat-production of the individual.

The second column shows the great variability in basal heat-production from individual to individual. The variabilities range from 142 to 245 calories for men and from 150 to 165 calories for women. For the larger series 140 to 230 calories for men and 150 to 160 calories for women may be taken as the variabilities expressed in round numbers. It is evident that with such large variations in the daily basal metabolism of the normal individual the prediction of the heat-production of an *individual* subject will always have a high probable error—that is, a limited trustworthiness. In infants the standard deviations are about 21 to 23 calories per day (table 5).

In speaking of standard deviations of 140 to 230 calories for adults and of 21 to 23 calories for infants as large, one must not forget that these are for organisms giving daily average heat-productions of 1300 to 1650 calories for the adult and of 140 to 145 calories per day for the infantile state. If the standard deviations be expressed as percentages of the average daily heat-production we have the constants in the third column of table 5 for the infants and table 16 for the adults. To gain a definite idea of the relative variability of basal metabolism as compared with other more familiar physical magnitudes and physiological activities, it seems worth while to examine these constants in some detail.

First of all we note that the values range from 8.85 to 14.08 per cent for men and from 11.05 to 12.31 for the women, with constants for the whole series of data for the two sexes of 12.54 ± 0.52 for the men and 11.50 ± 0.55 for women. These values can not, with due regard to their probable errors, be asserted to differ significantly.

In the infants the coefficients of variation are somewhat higher, being 14.46 for the boy babies, 16.54 for the girl babies, and 15.49 for infants irrespective of sex. The difference between the two sexes is 2.08 ± 1.59, which is statistically insignificant and hence can not be regarded as indicative of a real physiological difference in variability of heat production between the sexes.

Comparing with other characters dealt with in this volume, we note that the metabolism of a group of individuals is from 2 to 3 times as variable as their stature, (table 8), but is not in any instance as variable as their body-weight (table 11). The relative variability of total heat-production is also, roughly speaking, from 20 to 25 per cent greater than body-surface area as measured by the Meeh formula (table 50). This point is of particular interest because of the fact that if heat-production were proportional to body-surface area, as maintained by many, the variability of these two measures should be the same. To a full consideration of this matter we shall return in Chapter VI.

These values are by no means as large as those which have been found for the variation of weight of internal organs in man. For example, Greenwood's[81] series shows coefficients of variation for the weight of the spleen of 38.2 and 50.6 per cent in normal and hospital populations. The same author finds a coefficient of variation of from 22.2 to 32.4 for the weight of the heart in hospital series and 17.7 in normal series. For the weight of the kidneys the coefficients are 21.1 to 24.6 for hospital and 16.8 for normal subjects. For the weights of the liver the constant is 20.8 to 21.1 for hospital series and 14.8 for healthy series.

Comparison of the relative variability of total heat-production with that of another physiological measurement, pulse-rate, shows that the two are roughly of the same order of magnitude. In the whole series of men total heat-production shows a variation of 12.54 ± 0.52 as compared with 10.99 ± 0.48 for pulse-rate, a difference of $+1.55 \pm 0.71$. In the whole series of women the comparable values are 11.50 ± 0.55 for heat-production and 12.01 ± 0.61 for pulse-rate, a difference of -0.51 ± 0.82. Thus the two differences for total series are opposite in sign, and neither can be looked upon as statistically significant in comparison with its probable error. Unfortunately pulse-rate is not available for all the individuals but this can hardly affect the correctness of the conclusion.

These comparisons with characters the variability of which is more familiar to the general biologist and physiologist, will perhaps indicate the relative magnitude of variation in total heat-production. The individual constants will be extensively used in the analysis of the various problems in the following chapters.

4. RECAPITULATION.

This chapter has had a threefold purpose.

A. To describe the measurements dealt with and to give the symbols by which they are designated in the subsequent discussion.

B. To give protocols of the actual measurements analyzed in subsequent sections. These comprise 51 male and 43 female infants

[81] Greenwood, Biometrika, 1904, 3, p. 465; Greenwood and Brown, *loc. cit.*, 1913, 9, p. 481.

and 136 men and 103 women. Of the adult records, those for 47 men and 35 women are published here for the first time.

C. To test the normality of our series of data, upon which physiological generalizations are to be based.

In considering this problem we have emphasized a conception of normality which differs somewhat from that heretofore maintained by other students of metabolism.

1. Realizing that *practically* the greatest importance of a knowledge of the basal metabolism of the normal individual is for the calculation of the 24 hours' requirement of the healthy individual and for the establishment of control values to be used as a basis for conclusions concerning the influence of special conditions or the incidence of specific diseases on metabolism, we have made it a condition of inclusion in our series that the individual be in presumably good health.

2. Since the populations which must be considered in rationing problems are made up of physically varied individuals, it is essential that any generalization which shall be applicable to these populations be grounded on series of individuals showing like range of physical dimensions. Since individuals in the hospital ward do not conform to any individual physiologists conception of "the normal man," but represent the entire range of physical dimensions and proportions, the non-pathological controls which are to be used as a basis of comparison should show a comparable range of physical dimensions and proportions.

3. Since some of the theoretical physiological problems to be considered have to do with the relationship between variations in physical characteristics and physiological activities, it is essential that the subjects investigated show average dimensions and variability and correlation of dimensions *typical of men and women as a class.*

Thus, when we speak of a series of normal individuals we do not mean a group of men similar to the figures in the Laocoon or a group of women conforming to the Venus of Milo, but those who are in presumably good health and otherwise are typical of men or women of the same race as the anthropologist knows them. With such a conception of normality it is impossible to discard individuals merely because they are too heavy in proportion to their stature or too tall in proportion to their weight.

On the other hand, it is of course quite as unallowable to form standard series containing disproportionate numbers of very fat or very lean individuals, as it is to discard both of these extremes and include only those of average proportions.

The "normality" of such series must be judged by comparison of their statistical constants with those of men and women at large. Such criteria have been applied to the data discussed in this volume.

This conception of normality must, we believe, be generally accepted if investigations of human metabolism are to yield the results of the greatest theoretical interest and practical importance.

CHAPTER IV.

ON THE INTERRELATIONSHIP OF VARIOUS PHYSICAL AND PHYSIOLOGICAL MEASUREMENTS.

Our knowledge, in quantitative terms, of the degree of interrelationship of the various physical characteristics of man is now very extensive indeed. Relatively little is known of the closeness of interdependence of physical magnitudes and physiological activities in series of individuals; yet it seems clear that this subject should receive careful quantitative treatment. Again, it seems to us self-evident that the determination of true quantitative measures of the degree of interdependence of the various physiological activities should make possible material advances in our knowledge of these functions.

This position will be justified whatever the outcome of actual investigations. If it be shown that various physiological measurements are correlated with physical characteristics, such relationships must form part and parcel of our system of knowledge concerning human morphology and physiology. If, on the other hand, it be found that between certain of the physical and physiological measurements there is no sensible relationship, it will be clear that the physical characteristics need not be considered in the selection of individuals which may be regarded as comparable for use in studies of such physiological activities as have been shown to be uncorrelated with physical characteristics.

Again, if various physiological activities be shown to be correlated, a knowledge of the intimacy of the interdependence of a great variety of physiological functions will contribute materially to our comprehension of the human body as a coördinated whole. Since our general experience of comparative and experimental physiology is such as to render it rather difficult to conceive of an entire lack of interdependence between the great majority of the physiological activities of the organism, those which show minimum intensities of relationships will be of particular interest.

In this chapter we shall discuss the correlation between the two physical characteristics available, stature and body-weight and various physiological measurements pertinent to metabolism investigations. Another physical characteristic is body-surface area, but since this is to receive special attention in a subsequent chapter, it will be left out of account here.

We shall, first of all, deal with the relationship between stature and weight on one hand and pulse-rate on the other. We shall then con-

sider measures of the degree of interdependence of pulse-rate and gaseous exchange and total heat-production. With these data at our disposal, we shall proceed to a consideration of the relationship between physical characters and metabolism.

Since the physical characteristics, stature and weight, have been shown to be correlated, it is sometimes necessary in discussing the relationship between either of these and physiological characters to anticipate results to be given in detail later.

1. WEIGHT AND PULSE-RATE.

In the series of normal infants we find the correlation between weight and pulse-rate, r_{wp}, and the test of significance furnished by the ratio of the constant to its probable error, r/E_r:

For males	$N=51$,	$r_{wp}=0.3114\pm0.0853$,	$r/E_r=3.65$
For females	$N=43$,	$r_{wp}=0.1570\pm0.1003$,	$r/E_r=1.56$
Difference		0.1544 ± 0.1317	
For both	$N=94$,	$r_{wp}=0.2289\pm0.0659$,	$r/E_r=3.47$

The coefficient for females is only about 1.5 times as large as its probable error, and so can not be considered to prove that there is any correlation whatever between pulse-rate and body-weight.

The value for boys is numerically larger than that for girls, but in comparison with its probable error the difference between the constants for the two sexes is not statistically significant.

The constant for the male babies and that for male and female babies suggest a real interdependence between weight and pulse-rate, but the number of individuals is, statistically speaking, so small that caution must be used in asserting that in male infants as a class there is any relationship between pulse-rate and body-weight.

Even if one be inclined to accept these correlations as indicating a real physiological relationship between body-weight and pulse-rate, he must remember that it can not be asserted, without further analysis, that there is a direct biological nexus between body-weight as such and pulse-rate. Body-weight is correlated with stature, and it is quite possible that the observed correlation between body-weight and pulse-rate is in part at least the resultant of correlations between stature (length) and body-weight and between stature (length) and pulse-rate.

Furthermore, one must remember that all these variables may change with age, and that in any detailed investigation covering the whole period of life such age changes must be fully taken into account.

Consider first of all the correction to the correlation between weight and pulse-rate to be made for stature. The partial correlation

between weight and pulse-rate for constant stature is required. Thus

$$_sr_{wp} = \frac{r_{wp} - r_{ws}r_{sp}}{\sqrt{1-r_{ws}^2}\sqrt{1-r_{sp}^2}}$$

gives the desired constants. In the infants the results are:

For males. . . . . $_sr_{wp} = 0.3073 \pm 0.0855$
For females. . . . . $_sr_{wp} = 0.1442 \pm 0.1007$
For both. . . . . $_sr_{wp} = 0.2167 \pm 0.0663$

Correction for stature has slightly but not materially reduced the correlation between body-weight and pulse-rate. The partial correlations for the males and for the males and females are about 3.6 times as large as their probable errors and may be statistically significant.

The correlations between body-weight, w, and pulse-rate, p, for the several adult series and the partial correlations between body-weight and pulse-rate for constant stature appear in table 17.

TABLE 17.—*Correlation between weight and pulse-rate and partial correlation between weight and pulse-rate with stature constant and with age constant.*

Series.	N	Correlation between weight and pulse-rate r_{wp}	$\frac{r_{wp}}{E_{r_{wp}}}$	Partial correlation between weight and pulse-rate $_sr_{wp}$	$\frac{_sr_{wp}}{E_{_sr_{wp}}}$	Partial correlation between weight and pulse-rate $_ar_{wp}$	$\frac{_ar_{wp}}{E_{_ar_{wp}}}$
Men.							
Original series:							
Athletes	16	+0.1579±0.1644	0.96	−0.3548±0.1474	2.41	+0.0673±0.1679	0.40
Others	62	−0.1634±0.0834	1.96	−0.0881±0.0850	1.04	−0.1904±0.0826	2.31
Whole series	88	+0.0055±0.0719	0.08	−0.0402±0.0719	0.56	+0.0055±0.0719	0.08
Gephart and Du Bois selection	71	−0.1458±0.0783	1.86	−0.0611±0.0797	0.77	−0.1608±0.0780	2.06
First supplementary series	28	+0.0786±0.1267	0.62	+0.0957±0.1263	0.76	+0.0894±0.0126	7.10
Original and first supplementary series	116	+0.0162±0.0626	0.26	−0.0303±0.0626	0.48	+0.0200±0.0626	0.32
Other than Gephart and Du Bois selection	50	+0.1884±0.0920	2.05	+0.0198±0.0954	0.21	+0.2121±0.0949	2.23
All men of three series	121	+0.0365±0.0612	0.60	−0.0207±0.0613	0.34	+0.0430±0.0612	0.70
Women.							
Original series	68	−0.2942±0.0747	3.94	−0.2835±0.0752	3.77	−0.2971±0.0746	3.98
Supplementary series	22	−0.0872±0.1427	0.61	−0.1077±0.1421	0.76	−0.1423±0.1409	1.01
Both series	90	−0.2483±0.0667	3.72	−0.2398±0.0670	3.58	−0.2359±0.0671	3.52

The constants are both low and irregular, sometimes negative and sometimes positive in sign. They indicate practically no relationship between body-weight and pulse-rate in men, but suggest a slight negative relationship in women, *i.e.*, that slower pulse is associated with greater body-weight. With regard to their probable errors the correlations are practically without exception statistically insignificant in magnitude. Only the original series of women and (through its influence) the total series of women show a correlation over 3 times as large as its probable error.

If the influence of stature upon the correlation between body-weight and pulse-rate be eliminated by determining the partial correlation between body-weight and pulse-rate for constant stature, the results are practically unchanged. The partial correlations, like the correlations, are low and irregular in magnitude. Only the original and the total series of women may be considered possibly significant in comparison with their probable errors.

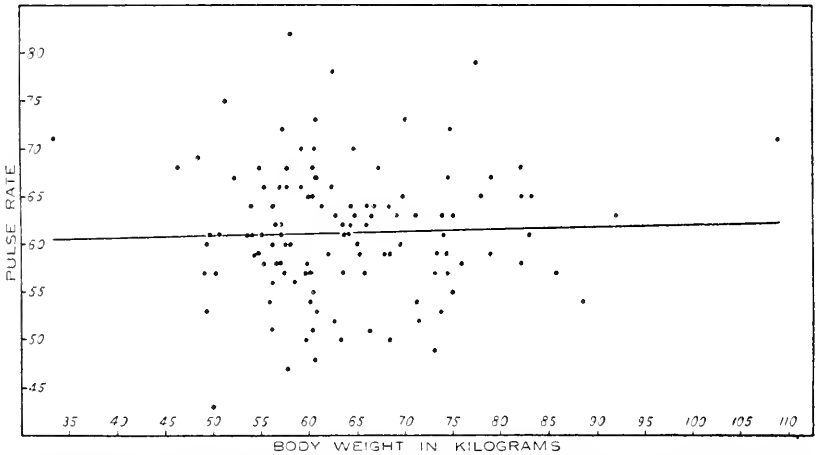

DIAGRAM 5.—Distribution of individual men with respect to body-weight and pulse-rate. Note the lack of relationship as shown by wide scatter of individual measurements and slight slope of the line. Compare diagrams 6 and 7.

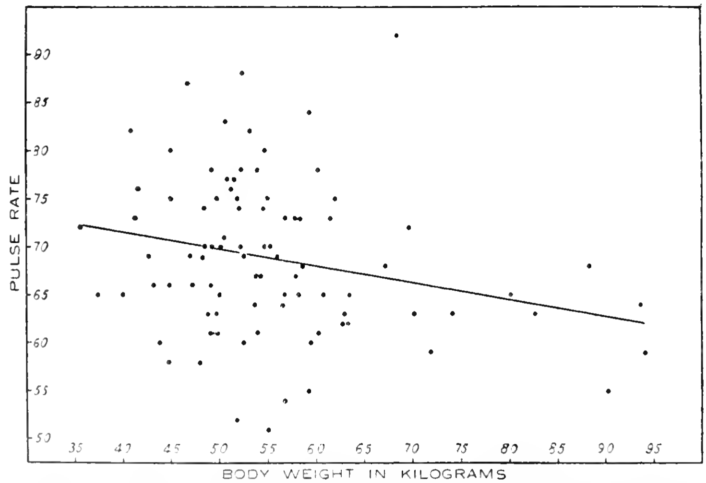

DIAGRAM 6.—Relationship between body-weight and pulse-rate in women. Compare diagrams 5 and 7.

Correcting for the possible influence of age by evaluating

$$ {}_{a}r_{wp} = \frac{r_{wp} - r_{aw} r_{ap}}{\sqrt{1 - r_{aw}^2}\sqrt{1 - r_{ap}^2}} $$

we find the values given in comparison with the gross correlations in the final column of table 17.

Correction for age has not materially changed the values.

The most interesting point about these results is the persistently negative values for the women. We shall note that women seem to differ from men in several correlations to be considered later.

The distribution of the individual observations for the grand total male ($N=121$) and grand total female ($N=90$) series is shown in the two scatter diagrams 5 and 6. The straight lines are given by the equations:

Men, $p=59.7782+0.0232\,w$ Women, $p=78.5659-0.1775\,w$

The slightness of the slope of the lines and the wide scatter of the dots about the theoretical mean values show clearly the insignificance of the relationship between body-weight and pulse-rate in our series.

2. STATURE AND PULSE-RATE.

In the series of infants the correlation between stature (length) and pulse-rate is:

For males	$N=51$	$r_{sp}=0.1529\pm0.0922$	$r/E_r=1.66$
For females	$N=43$	$r_{sp}=0.0981\pm0.1019$	$r/E_r=0.96$
Difference		0.0548 ± 0.1374	
For both	$N=94$	$r_{sp}=0.1294\pm0.0684$	$r/E_r=1.89$

The value for the males is higher, but in comparison with its probable error certainly not significantly higher, than that for the females. Neither of the constants taken alone can be considered to differ significantly from zero. That all three are positive in sign suggests that there may be some slight positive relationship between stature and pulse-rate in infants.

But pulse-rate is more closely correlated in infants with body-weight. Thus comparing the correlations of stature and weight we have the following values:

	For stature and pulse-rate.	*For weight and pulse-rate.*	*Difference in correlation.*
Males	0.1529 ± 0.0922	0.3114 ± 0.0853	0.1585 ± 0.1256
Females	0.0981 ± 0.1019	0.1570 ± 0.1003	0.0589 ± 0.1430
Difference	0.0548 ± 0.1374	0.1544 ± 0.1317	
For both	0.1294 ± 0.0684	0.2289 ± 0.0659	0.0995 ± 0.0950

For both males and females the correlation between weight and pulse-rate is higher (but in comparison with its probable error not significantly higher) than that between length and pulse-rate.

Since stature and weight are closely correlated, *i.e.*, in infants

For males	$r_{sw}=0.7703\pm0.0384$
For females	$r_{sw}=0.8642\pm0.0260$
For both	$r_{sw}=0.8209\pm0.0227$

it is necessary to ascertain the influence of the correlation between weight and pulse-rate upon that between stature and pulse-rate.

Determining the correlation between stature and pulse-rate for constant weight by the partial correlation formula

$$ {}_{w}r_{sp} = \frac{r_{sp} - r_{sw} r_{wp}}{\sqrt{1 - r_{sw}^2}\sqrt{1 - r_{wp}^2}} $$

we have:

	r_{sp}	${}_{w}r_{sp}$	${}_{w}r_{sp} - r_{sp}$
In males	0.1529 ± 0.0922	-0.1436 ± 0.0925	-0.2965 ± 0.1306
In females	0.0981 ± 0.1019	-0.0756 ± 0.1023	-0.1737 ± 0.1444
In both sexes	0.1294 ± 0.0684	-0.1053 ± 0.0688	-0.2347 ± 0.0973

Thus correction for weight has reversed the sign of the correlation between stature and pulse-rate in infants. The partial correlations are negative in sign, but neither can be considered statistically significant in comparison with its probable error.

We now turn to the data for adults. These appear in the first column of constants of table 18.

TABLE 18.—*Correlation between stature and pulse-rate and partial correlation between stature and pulse-rate with weight constant and with age constant.*

Series.	N	Correlation between stature and pulse-rate r_{sp}	$\frac{r_{sp}}{E_{r_{sp}}}$	Partial correlation between stature and pulse-rate ${}_{w}r_{sp}$	$\frac{{}_{w}r_{sp}}{E_{{}_{w}r_{sp}}}$	Partial correlation between stature and pulse-rate ${}_{a}r_{sp}$	$\frac{{}_{a}r_{sp}}{E_{{}_{a}r_{sp}}}$
Men.							
Original series:							
Athletes	16	$+0.5376 \pm 0.1199$	4.48	$+0.6021 \pm 0.1075$	5.60	$+0.4883 \pm 0.1284$	3.80
Others	62	-0.2108 ± 0.0818	2.58	-0.1607 ± 0.0834	1.93	-0.2157 ± 0.0817	2.64
Whole series	88	$+0.0728 \pm 0.0715$	1.02	$+0.0829 \pm 0.0714$	1.16	$+0.0486 \pm 0.0717$	0.68
Gephart and Du Bois selection	71	-0.1498 ± 0.0783	1.91	-0.0703 ± 0.0796	0.88	-0.1502 ± 0.0782	1.92
First supplementary series	28	$+0.0200 \pm 0.1274$	0.16	-0.0583 ± 0.1270	0.46	$+0.0240 \pm 0.1274$	0.19
Original and first supplementary series	116	$+0.0710 \pm 0.0623$	1.14	$+0.0754 \pm 0.0623$	1.21	$+0.0550 \pm 0.0624$	0.88
Other than Gephart and Du Bois selection	50	$+0.3339 \pm 0.0848$	3.94	$+0.2814 \pm 0.0878$	3.21	$+0.3102 \pm 0.0862$	3.60
All men of three series	121	$+0.0916 \pm 0.0608$	1.51	$+0.0865 \pm 0.0609$	1.42	$+0.0772 \pm 0.0612$	1.27
Women.							
Original series	68	-0.0844 ± 0.0812	1.04	-0.0214 ± 0.0817	0.26	-0.0738 ± 0.0813	0.91
Supplementary series	22	-0.0014 ± 0.1438	0.01	$+0.0635 \pm 0.1432$	0.44	-0.0455 ± 0.1435	0.32
Both series	90	-0.0669 ± 0.0708	0.94	$+0.0107 \pm 0.0071$	1.51	-0.0542 ± 0.0709	0.76

The values are partly negative and partly positive in sign. They vary widely in magnitude. For the athletes the constant is positive and of medium magnitude, but the 62 other men give a negative correlation of the order $r = -0.2$. As a result, the correlation for the whole series is, in comparison with its probable error, sensibly zero. The same is true for the first supplementary series of men and for the whole series of men (121 in number) for which records of both stature and pulse-rate are available. For all three of these larger series the corre-

lation is, however, positive in sign, indicating that taller individuals have a more rapid pulse. If, however, one turns to the Gephart and Du Bois selection of male subjects he finds a negative correlation of the order $r = -0.15$, thus indicating that the taller men have a less rapid pulse. This is also the relationship suggested by the constants for the women, who give a consistently negative but statistically insignificant correlation.

Inspection of the means obtained without grouping the values for stature—as given in diagram 7 for the total available men ($N = 121$) and for the total available women ($N = 90$)—shows (*a*) how widely scattered the average pulse-rates for any given stature are, and (*b*)

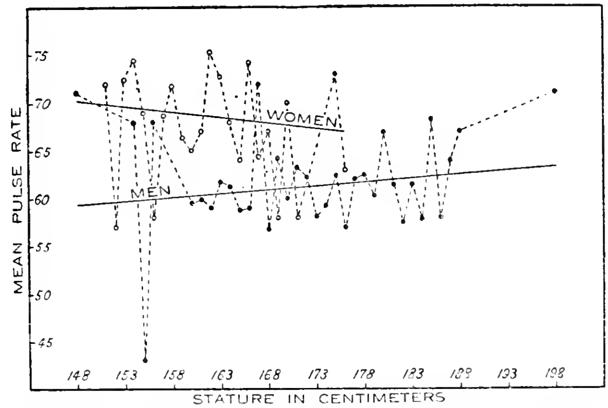

DIAGRAM 7.—Variation of mean basal pulse-rate with stature in men and women. Note extreme irregularity of means and different slopes of the straight lines in the two sexes. Compare diagrams 5 and 6 for body-weight and pulse-rate.

how slight is the change in average pulse-rate associated with differences in stature. The straight lines in the diagrams are due to the equations:

For men................	$N = 121$	$p = 47.7179 + 0.0783\,s$
For women............	$N = 90$	$p = 86.0430 - 0.1073\,s$

If the relationship between stature and pulse-rate be corrected for the correlation of weight with stature, we find the partial correlations between stature and pulse for constant weight, like the uncorrected correlations, are low in magnitude and irregular with regard to sign. The exception is the athletes, but these are too few in number to justify attaching much significance to the probable errors of the constants.

The partial correlations between stature and pulse-rate for constant age are given by

$$_a r_{sp} = \frac{r_{sp} - r_{as} r_{ap}}{\sqrt{1 - r_{as}^2}\,\sqrt{1 - r_{ap}^2}}$$

The results obtained by applying this formula appear in the final column of table 18.

Correction for age has not materially changed the values of the constants.

Summarizing the results of these various calculations we note that in male and female infants and in our male adults taken as a class there is a suggestion of positive correlation between stature and pulse-rate, *i.e.*, of an increase of pulse-rate with stature. In the adults this is, however, largely due to the athletes and the vegetarians in the original series. The Gephart and Du Bois selection of males and the female series suggest a negative relationship between stature and pulse-rate. Thus the results for infants and adults, if either are really biologically significant, indicate a different relationship at the two ages.

As far as the available data justify conclusions concerning the problem, they seem to indicate that there is only a very slight, if any, interdependence between stature and minimum or basal pulse-rate in man.

3. PULSE-RATE AND GASEOUS EXCHANGE.

Since it is well known that pulse-rate and gaseous exchange are closely related in the individual, it seems desirable to determine whether in a series of individuals at complete muscular repose and in the post-absorptive state a correlation between pulse-rate and gaseous exchange and between pulse-rate and total heat-production will be found to exist.

TABLE 19.—*Correlation between pulse-rate and gaseous exchange.*

Series.	N	Correlation between pulse-rate and carbon-dioxide r_{pc}	N	Correlation between pulse-rate and oxygen r_{po}	Difference $r_{po}-r_{pc}$
Men.					
Original series:					
Athletes	15	$+0.2981 \pm 0.1587$	16	$+0.2963 \pm 0.1538$	-0.0018 ± 0.2210
Others	62	$+0.0306 \pm 0.0856$	62	$+0.0718 \pm 0.0852$	$+0.0412 \pm 0.1208$
Whole series	87	$+0.1416 \pm 0.0709$	88	$+0.2045 \pm 0.0689$	$+0.0629 \pm 0.0989$
Gephart and Du Bois selection	70	$+0.0691 \pm 0.0802$	71	$+0.1197 \pm 0.0787$	$+0.0506 \pm 0.1125$
First supplementary series	28	$+0.1387 \pm 0.1250$	28	$+0.2085 \pm 0.1219$	$+0.0698 \pm 0.1746$
Original and first supplementary series	115	$+0.1482 \pm 0.0615$	116	$+0.1976 \pm 0.0602$	$+0.0494 \pm 0.0861$
Other than Gephart and Du Bois selection	50	$+0.2384 \pm 0.0900$	50	$+0.2788 \pm 0.0880$	$+0.0404 \pm 0.1259$
All men of three series	120	$+0.1539 \pm 0.0601$	121	$+0.2012 \pm 0.0588$	$+0.0473 \pm 0.0841$
Women.					
Original series	66	-0.0734 ± 0.0826	68	$+0.0318 \pm 0.0817$	$+0.1052 \pm 0.1162$
Supplementary series	22	$+0.4811 \pm 0.1105$	22	$+0.3656 \pm 0.1246$	-0.1155 ± 0.1665
Both series	88	$+0.0497 \pm 0.0717$	90	$+0.1331 \pm 0.0698$	$+0.0834 \pm 0.0100$

Table 19 gives the correlations between pulse-rate and oxygen consumption and pulse-rate and carbon-dioxide production, and the differences in these correlations, for the various series with which we have worked. The results are reasonably consistent in indicating a low but significant positive correlation between pulse-rate and oxygen consumption and pulse-rate and carbon-dioxide excretion, larger gaseous exchange being associated with more rapid pulse-rate.

In the original series of women we find a slight negative correlation between pulse-rate and gaseous exchange, the women with the slower pulse showing the higher carbon-dioxide excretion. For oxygen consumption the correlation is sensibly zero. The second series shows a substantial positive correlation. The slight negative relationship between pulse-rate and carbon-dioxide excretion in the original series of women naturally pulls down the positive correlation in the supplementary series, so that a resultant low positive correlation is obtained in the total series of women.

The correlation between pulse-rate and oxygen consumption is more intimate than that between pulse-rate and carbon-dioxide excretion.

If we determine the partial correlation between pulse-rate and gaseous exchange for constant body-weight by the formulas

$$_{w}r_{po}=\frac{r_{po}-r_{wp}r_{wo}}{\sqrt{1-r_{wp}^{2}}\sqrt{1-r_{wo}^{2}}} \qquad _{w}r_{pc}=\frac{r_{pc}-r_{wp}r_{wc}}{\sqrt{1-r_{wp}^{2}}\sqrt{1-r_{wc}^{2}}}$$

we find the results set forth in table 20.

TABLE 20.—*Comparison of partial correlations between pulse-rate and gaseous exchange for constant body-weight with gross correlations between pulse-rate and gaseous exchange.*

Series.	N	Partial correlation between pulse-rate and carbon-dioxide $_{w}r_{pc}$	$\frac{_{w}r_{pc}}{E_{\,w}r_{pc}}$	Difference $_{w}r_{pc}-r_{pc}$	N	Partial correlation between pulse-rate and oxygen $_{w}r_{po}$	$\frac{_{w}r_{po}}{E_{\,w}r_{po}}$	Difference $_{w}r_{po}-r_{po}$
Men.								
Original series:								
Athletes	15	+0.5640±0.1188	4.75	+0.2659	16	+0.5205±0.1229	4.24	+0.2242
Others	62	+0.1540±0.0836	1.84	+0.1234	62	+0.2261±0.0813	2.78	+0.1543
Whole series	87	+0.1835±0.0699	2.63	+0.0419	88	+0.3342±0.0639	5.23	+0.1297
Gephart and Du Bois selection	70	+0.2931±0.0737	3.98	+0.2240	71	+0.3802±0.0685	5.55	+0.2605
First supplementary series	28	+0.1278±0.1254	1.02	−0.0109	28	+0.2865±0.1170	2.45	+0.0780
Original and first supplementary series	115	+0.2207±0.0598	3.69	+0.0725	116	+0.3207±0.0562	5.71	+0.1231
Other than Gephart and Du Bois selection	50	+0.1488±0.0933	1.60	−0.0896	50	+0.2244±0.0906	2.48	−0.0544
All men of three series	120	+0.2027±0.0590	3.44	+0.0488	121	+0.2938±0.0560	5.25	+0.0926
Women.								
Original series	66	+0.2242±0.0788	2.84	+0.2976	68	+0.4002±0.0687	5.83	+0.3684
Supplementary series	22	+0.6485±0.0833	7.79	+0.1674	22	+0.5420±0.1016	5.34	+0.1764
Both series	88	+0.2006±0.0690	2.91	+0.1509	90	+0.3781±0.0609	6.21	+0.2450

In general, correction for body-weight has increased the intensity of relationship between pulse-rate and gaseous exchange. This indicates that the relationship is a real physiological one, and not merely the incidental resultant of the correlation of both pulse-rate and gaseous exchange with body-mass. The partial correlations for the two series of women are now in agreement as far as signs are concerned. These relationships will be analyzed more minutely on the basis of total calories produced.

4. PULSE-RATE AND TOTAL HEAT-PRODUCTION.

Table 21 gives the coefficients for pulse-rate and total heat-production and for pulse-rate and total heat-production per kilogram of body-weight.

The correlations for pulse-rate and total heat are all positive in sign but numerically low and extremely variable in magnitude. In the latter regard they are in full agreement with the constants for pulse-rate and gaseous exchange, as is to be expected from the method of computing the heat-production from gaseous exchange.

TABLE 21.—*Comparison of correlations between pulse-rate and gross heat-production and between pulse-rate and heat-production per kilogram of body-weight.*

Series.	N	Pulse-rate and total heat r_{ph}	$r_{ph}/E_{r_{ph}}$	Pulse-rate and heat per kilogram of body-weight r_{ph_k}	$r_{ph_k}/E_{r_{ph_k}}$	Difference $r_{ph_k}-r_{ph}$	Diff./$E_{diff.}$
Men.							
Original series:							
Athletes	16	0.3041 ± 0.1530	1.99	0.2783 ± 0.1556	1.79	-0.0258 ± 0.2182	0.12
Others	62	0.0650 ± 0.0853	0.76	0.2947 ± 0.0782	3.77	$+0.2297\pm0.1157$	1.99
Whole series	88	0.1986 ± 0.0691	2.87	0.2722 ± 0.0666	4.09	$+0.0736\pm0.0960$	0.77
Gephart and Du Bois selection	71	0.1103 ± 0.0791	1.39	0.4048 ± 0.0669	6.05	$+0.2945\pm0.1036$	2.84
First supplementary series	28	0.1964 ± 0.1226	1.60	0.2179 ± 0.1214	1.79	$+0.0215\pm0.1725$	0.12
Original and first supplementary series	116	0.1887 ± 0.0604	3.12	0.2583 ± 0.0584	4.42	$+0.0696\pm0.0840$	0.83
Other than Gephart and Du Bois selection	50	0.2721 ± 0.0883	3.08	0.0613 ± 0.0950	0.65	-0.2108 ± 0.1297	1.63
All men of three series	121	0.1928 ± 0.0590	3.27	0.2285 ± 0.0581	3.93	$+0.0357\pm0.0828$	0.43
Women.							
Original series	68	0.0155 ± 0.0818	0.19	0.4621 ± 0.0643	7.19	$+0.4466\pm0.1040$	4.29
Supplementary series	22	0.3923 ± 0.1217	3.22	0.3317 ± 0.1280	2.59	-0.0606 ± 0.1766	0.34
Both series	90	0.1224 ± 0.0700	1.75	0.4240 ± 0.0583	7.27	$+0.3016\pm0.0910$	3.31

Before deciding that physiologically there is a very slight correlation between pulse-rate and gaseous exchange or pulse-rate and total heat-production one must remember that the measures of gas volume are to a considerable degree dependent upon the absolute size of the individuals upon which they are based. To determine more exactly the true physiological interdependence between pulse-rate and total heat-production, some correction for the absolute size of the organism must, therefore, be made. This may be done in either of two ways:

First, one may correct for size directly in the case of each individual by reducing gross heat-production to calories per kilogram or calories per square meter of body-surface.

Second, one may work with final constants merely by determining the partial correlation between pulse-rate and total heat-production for constant stature, constant body-weight, or constant stature and body-weight.

With the exception of the small series of athletes and the group other than the Gephart and Du Bois selection among the men and the supplementary series of women, all of the values are raised when the influence of extreme variation in body-size is to some extent elimin-

ated by expressing heat-production in calories per kilogram of body-weight. The magnitude of the difference between the correlations for pulse and total heat and pulse and heat per kilogram of body-weight is not large. In no series of men excepting the Gephart and Du Bois selection can the difference be looked upon as statistically significant in comparison with its probable error. Nevertheless the consistency of the results from the larger series certainly indicates that correction for the influence of body-mass upon total heat-production has increased somewhat the closeness of interdependence between the rate of heart-beat and metabolism. In the women the original series and the total series show significantly larger positive correlations between pulse-rate and heat per kilogram than between pulse-rate and total heat-production. This is not, however, true of the supplementary series.

TABLE 22.—*Comparison of correlation between pulse-rate and total heat-production and between pulse-rate and heat-production per square meter of body-surface.*

Series.	N	Pulse-rate and heat per square meter by Meeh formula r_{ph_M}	$\frac{r_{ph_M}}{E_{r_{ph_M}}}$	Difference $r_{ph_M}-r_{ph}$	$\frac{\text{Diff.}}{E_{diff.}}$	Pulse-rate and heat per square meter by Du Bois height-weight chart r_{ph_D}	$\frac{r_{ph_D}}{E_{r_{ph_D}}}$	Difference $r_{ph_D}-r_{ph}$	$\frac{\text{Diff.}}{E_{diff.}}$
Men.									
Original series:									
Athletes......	16	0.5779±0.1123	5.15	+0.2738±0.1223	2.24	0.2083±0.1613	1.29	−0.0958±0.2223	0.43
Others........	62	0.2847±0.0787	3.62	+0.2197±0.1160	1.89	0.3140±0.0772	4.07	+0.2490±0.1150	2.17
Whole series..	88	0.2820±0.0662	4.26	+0.0834±0.0957	0.87	0.3408±0.0636	5.36	+0.1422±0.0939	1.51
Gephart and Du Bois selection......	71	0.3835±0.0683	5.61	+0.2732±0.1045	2.61	0.3949±0.0676	5.84	+0.2846±0.1041	2.73
First supplementary series....	28	0.2836±0.1172	2.42	+0.0872±0.1696	0.51	0.2905±0.1167	2.49	+0.0941±0.1693	0.56
Original and first supplementary series.........	116	0.2754±0.0579	4.76	+0.0867±0.0836	1.04	0.3082±0.0567	5.44	+0.1195±0.0828	1.44
Other than Gephart and Du Bois selection..	50	0.1981±0.0916	2.16	−0.0740±0.1272	0.58	0.1590±0.0930	1.71	−0.1131±0.1282	0.88
All men of three series.........	121	0.2522±0.0574	4.39	+0.0594±0.0823	0.72	0.2837±0.0564	5.03	+0.0909±0.0816	1.11
Women.									
Original series...	68	0.4712±0.0636	7.41	+0.4557±0.1036	4.39	0.3663±0.0708	5.17	+0.3508±0.1082	3.24
Supplementary series.........	22	0.4705±0.1120	4.20	+0.0782±0.1654	0.47	0.5283±0.1037	5.09	+0.1360±0.1599	0.85
Both series......	90	0.4522±0.0566	7.99	+0.3298±0.0900	3.66	0.4020±0.0596	6.74	+0.2796±0.0919	3.04

Table 22 gives comparisons of the correlations between pulse-rate and total heat-production as given in table 21 and pulse-rate and heat-production per square meter of body-surface by the two surface-area formulas used in this memoir.

The same type of relationship as that seen in the comparison of the correlations for pulse-rate and gross heat-production and pulse-rate and relative heat-production on a weight basis is apparent.

The correlations between pulse-rate and calories per square meter of body-surface by both methods of measurement are higher than the correlations between pulse-rate and gross heat-production in every series except the athletes and the individuals other than the Gephart and Du Bois selection as estimated by the Du Bois height-weight chart and the individuals other than the Gephart and Du Bois selection as estimated by the Meeh formula. The differences in these anomalous series are smaller than their probable errors.

Since it has been shown in the preceding discussion that correction for body-size increases the intensity of the correlation between pulse-rate and heat-production, it is worth while to inquire which method of correction brings about the maximum intensity of interrelationship in these two physiological measurements.

TABLE 23.—*Comparison of correlations between pulse-rate and heat-production for body-size by various methods.*

Series.	N	Difference $r_{ph_M} - r_{ph_k}$	Difference $r_{ph_D} - r_{ph_k}$	Difference $r_{ph_M} - r_{ph_D}$
Men.				
Original series:				
Athletes	16	$+0.2996 \pm 0.1919$	-0.0700 ± 0.2241	$+0.3696 \pm 0.1965$
Others	62	-0.0100 ± 0.1109	$+0.0193 \pm 0.1099$	-0.0293 ± 0.1102
Whole series	88	$+0.0098 \pm 0.0939$	$+0.0686 \pm 0.0921$	-0.0588 ± 0.0918
Gephart and Du Bois selection	71	-0.0213 ± 0.0956	-0.0099 ± 0.0951	-0.0114 ± 0.0961
First supplementary series	28	$+0.0657 \pm 0.1687$	$+0.0726 \pm 0.1684$	-0.0069 ± 0.1654
Orig'al and first supplementary series	116	$+0.0171 \pm 0.0822$	$+0.0499 \pm 0.0814$	-0.0328 ± 0.0810
Other than Gephart and Du Bois selection	50	$+0.1369 \pm 0.1320$	$+0.0977 \pm 0.1329$	$+0.0392 \pm 0.1305$
All men of three series	121	$+0.0237 \pm 0.0817$	$+0.0552 \pm 0.0810$	-0.0315 ± 0.0805
Women.				
Original series	68	$+0.0091 \pm 0.0904$	-0.0958 ± 0.0956	$+0.1049 \pm 0.0952$
Supplementary series	22	$+0.1388 \pm 0.1701$	$+0.1966 \pm 0.1647$	-0.0578 ± 0.1526
Both series	90	$+0.0282 \pm 0.0813$	-0.0220 ± 0.0834	$+0.0502 \pm 0.0822$

This step involves (*a*) the comparison of the influence of correction for the two measures of surface with that of the influence of correction for body-weight and (*b*) the comparison of the two measures of surface-area themselves. The results are shown in table 23. These are very consistent throughout, although because of the smallness of several of the series the probable errors of the differences are very high.

With few exceptions it appears that the correlation between pulse-rate and heat-production per square meter of body-surface, whether measured by the Meeh formula or by the Du Bois height-weight chart, is higher than that between pulse-rate and heat per kilogram of body-weight. Again, a comparison of the correlation between pulse-rate and heat per square meter of body-surface by the two methods of measurement, suggests that the correlation with body-surface as measured by the Du Bois height-weight chart gives

numerically higher constants than those obtained by the use of the Meeh formula.

These results have an obvious bearing upon the so-called Rubner's or body-surface law, to be discussed in detail in Chapter VI.

5. WEIGHT AND GASEOUS EXCHANGE.

The correlation coefficients for body-weight and oxygen consumption and for body-weight and carbon-dioxide excretion appear in table 24. For both gases the correlations are for the most part of a rather high order of magnitude and, with certain exceptions to be discussed in a moment, of a high degree of consistency.

TABLE 24.—*Correlations between body-weight and gaseous exchange.*

Series.	N	Correlation between body-weight and carbon-dioxide r_{wc}	$\frac{r_{wc}}{E_{r_{wc}}}$	N	Correlation between body-weight and oxygen r_{wo}	$\frac{r_{wo}}{E_{r_{wo}}}$	Difference $r_{wo}-r_{wc}$	Diff. / $E_{diff.}$
Men.								
Original series:								
Athletes	15	0.9354±0.0218	42.91	16	0.9595±0.0134	71.60	+0.0241±0.0256	0.94
Others	62	0.5741±0.0574	10.00	62	0.6255±0.0521	12.01	+0.0514±0.0775	0.66
Whole series	88	0.7736±0.0289	26.77	89	0.8007±0.0257	31.16	+0.0271±0.0387	0.70
Gephart and Du Bois selection	71	0.7670±0.0329	23.31	72	0.7828±0.0308	25.42	+0.0158±0.0451	0.35
First supplementary series	28	0.8066±0.0445	18.13	28	0.8719±0.0306	28.49	+0.0653±0.0540	1.21
Original and first supplementary series	116	0.7812±0.0244	32.02	117	0.8179±0.0206	39.70	+0.0367±0.0319	1.15
Second supplementary series	19	0.5042±0.1154	4.37	19	0.5778±0.1031	5.60	+0.0736±0.1547	0.48
Other than Gephart and Du Bois selection	64	0.7537±0.0364	20.71	64	0.8040±0.0298	26.98	+0.0503±0.0470	1.07
All men of three series	135	0.7575±0.0247	30.67	136	0.7955±0.0212	37.52	+0.0380±0.0325	1.17
Women.								
Original series	66	0.7332±0.0384	19.09	68	0.7508±0.0357	21.03	+0.0176±0.0524	0.34
Supplementary series	35	0.4251±0.0934	4.55	35	0.4583±0.0901	5.09	+0.0332±0.1298	0.26
Both series	101	0.6266±0.0408	15.36	103	0.5950±0.0429	13.87	−0.0316±0.0592	0.53

Generally speaking, the correlations for both weight and oxygen consumption and weight and carbon-dioxide production are of the order $r=0.75$ in men—that is to say of three-quarters of perfect interdependence. This is also true in the original series of women. The second series, of only 35 women, shows a much lower degree of interdependence, with the result that the total women show a correlation of the order $r=0.60$.

Among the men the small second supplementary series shows the lowest relationship, measured by a coefficient of about the same order as those found in the women.

We shall consider the relative values of the correlations between physical characters and oxygen consumption and carbon-dioxide production, and the relative magnitudes of the correlations for weight and gaseous exchange and stature and gaseous exchange after the

relationship between stature and gaseous exchange has been discussed in section 6.

The characteristic equations showing the change in gas volume with a variation of 1 kilogram of body-weight are given in table 25

TABLE 25.—*Straight-line regression equations showing relationship of gaseous exchange to body-weight*

Series.	N	Regression of CO_2 on body-weight.	N	Regression of O_2 on body-weight.
Men.				
Original series:				
Athletes	15	$C = 59.40+2.33\,W$	16	$O = 77.63+2.56\,W$
Others	62	$C = 125.10+1.05\,W$	62	$O = 138.91+1.46\,W$
Whole series	88	$C = 71.88+1.93\,W$	89	$O = 95.82+2.16\,W$
Gephart and Du Bois selection	71	$C = 60.55+2.11\,W$	72	$O = 83.44+2.36\,W$
First supplementary series	28	$C = 74.02+1.84\,W$	28	$O = 59.74+2.73\,W$
Original and first supplementary series	116	$C = 71.73+1.92\,W$	117	$O = 87.30+2.29\,W$
Second supplementary series	19	$C = 104.32+1.47\,W$	19	$O = 103.99+2.00\,W$
Other than Gephart and Du Bois selection	64	$C = 81.23+1.78\,W$	64	$O = 90.41+2.23\,W$
All men of three series	135	$C = 73.98+1.89\,W$	136	$O = 88.48+2.27\,W$
Women.				
Original series	66	$C = 87.19+1.30\,W$	68	$O = 114.31+1.49\,W$
Supplementary series	35	$C = 123.99+0.62\,W$	35	$O = 134.12+0.95\,W$
Both series	101	$C = 101.93+1.02\,W$	103	$O = 128.05+1.17\,W$

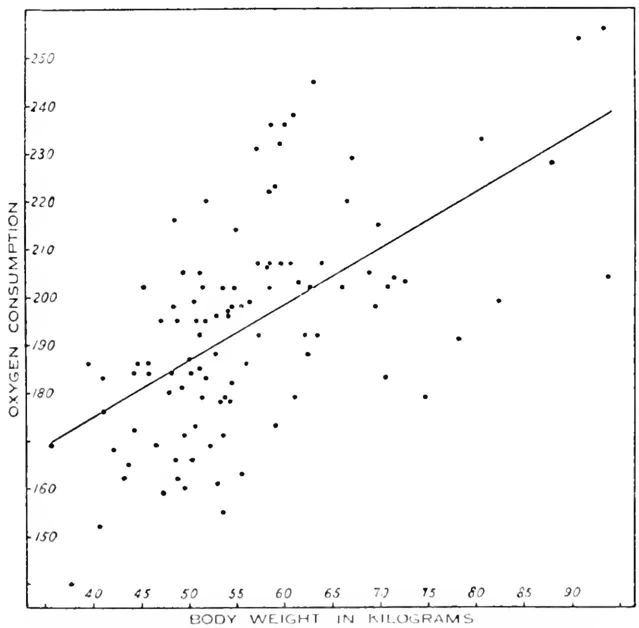

DIAGRAM 8.—Relationship between body-weight and oxygen consumption by women.

and represented graphically in diagrams 8 and 9. The results show that in the women the increase in oxygen consumption ranges from 0.95 to 1.49 c.c. for each kilogram of weight, whereas in the series of men

the increase varies from 1.46 to 2.73 c.c. for each kilogram of weight. The increase in the volume of CO_2 with increase in body-weight is in every instance less than the increase in the volume of O_2 with body-weight. Thus, in the women CO_2 production increases 0.62 c.c. per kilogram of weight in the supplementary series and 1.30 c.c. per kilogram of weight in the original series. In the larger series of men the increase in CO_2 output per kilogram of body weight ranges from 1.05 to 2.11 c.c. For the total series oxygen consumption increases about 1.17 c.c. in women and 2.27 c.c. in men for each kilogram of body-weight. Carbon-dioxide excretion increases about 1.02 c.c. in the

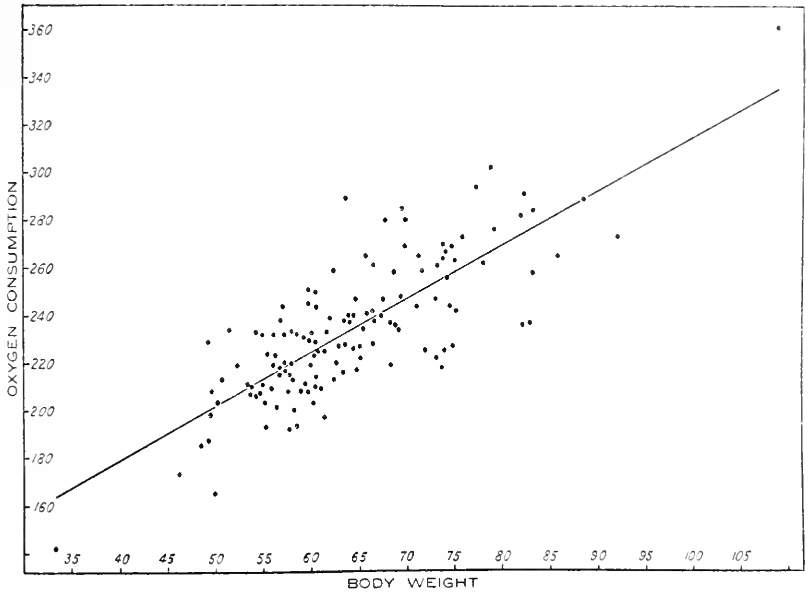

DIAGRAM 9.—Relationship between body-weight and oxygen consumption by men.

women and 1.89 c.c. in the men. This result would be expected from the fact that the respiratory quotient is practically always less than unity.

The significance of the differences in the exchange of the two gases will be discussed below. The difference between the two sexes will be treated on the basis of total heat-production in Chapter VII.

6. STATURE AND GASEOUS EXCHANGE.

The correlations between stature and gaseous exchange appear in table 26. The coefficients for the relationship between stature and both oxygen consumption and carbon-dioxide production in men are of medium or moderately high value and, considering the relatively few individuals (in the statistical, not the physiological, sense), are remarkably consistent throughout.

The most conspicuous feature of this table is the low value of the correlations for the women as compared with the men. Expressing these results in terms of regression we have the straight-line equations in table 27. The second constant in these equations shows that in

TABLE 26.—*Comparison of correlations of oxygen consumption and of carbon-dioxide excretion with stature.*

Series.	N	Correlation between stature and carbon-dioxide r_{sc}	$\frac{r_{sc}}{E_{r_{sc}}}$	N	Correlation between stature and oxygen r_{so}	$\frac{r_{so}}{E_{r_{so}}}$	Difference $r_{so}-r_{sc}$	$\frac{\text{Diff.}}{E_{diff.}}$
Men.								
Original series:								
Athletes	15	0.7677±0.0715	10.74	16	0.7798±0.0661	11.80	+0.0121±0.0974	0.12
Others	62	0.3830±0.0730	5.25	62	0.4287±0.0699	6.13	+0.0457±0.1011	0.45
Whole series	88	0.6013±0.0459	13.10	89	0.6063±0.0452	13.41	+0.0050±0.0644	0.08
Gephart and Du Bois selection	71	0.5699±0.0540	10.55	72	0.5974±0.0511	11.69	+0.0275±0.0743	0.37
First supplementary series	28	0.7179±0.0618	11.62	28	0.6972±0.0655	10.64	−0.0207±0.0901	0.23
Original and first supplementary series	116	0.6065±0.0396	15.32	117	0.6190±0.0385	16.08	+0.0125±0.0552	0.23
Second supplementary series	19	0.4102±0.1287	3.19	19	0.5840±0.1020	5.73	+0.1738±0.1639	1.06
Other than Gephart and DuBois selection	64	0.6019±0.0538	11.19	64	0.6271±0.0512	12.25	+0.0252±0.0743	0.34
All men of three series	135	0.5882±0.0380	15.48	136	0.6140±0.0360	17.06	+0.0258±0.0523	0.49
Women.								
Original series	66	0.2416±0.0782	3.09	68	0.1918±0.0788	2.43	−0.0498±0.1110	0.45
Supplementary series	35	0.2937±0.1042	2.82	35	0.3182±0.1025	3.10	+0.0245±0.1460	0.17
Both series	101	0.2575±0.0627	4.11	103	0.2331±0.0628	3.71	−0.0244±0.0887	0.28

TABLE 27.—*Equations showing variation of gaseous exchange with stature.*

Series.	N	Regression of CO_2 on stature.	N	Regression of O_2 on stature.
Men.				
Original series:				
Athletes	15	$C=-219.55+2.56S$	16	$O=-242.65+2.87S$
Others	62	$C=+\ 31.69+0.93S$	62	$O=+\ 2.33+1.33S$
Whole series	88	$C=-160.51+2.07S$	89	$O=-153.32+2.25S$
Gephart and Du Bois selection	71	$C=-136.80+1.91S$	72	$O=-140.18+2.16S$
First supplementary series	28	$C=-177.44+2.10S$	28	$O=-258.58+2.80S$
Original and first supplementary series	116	$C=-155.98+2.03S$	117	$O=-170.27+2.34S$
Second supplementary series	19	$C=-113.11+1.81S$	19	$O=-293.91+3.05S$
Other than Gephart and DuBois selection	64	$C=-164.04+2.08S$	64	$O=-206.60+2.55S$
All men of three series	135	$C=-152.74+2.01S$	136	$O=-177.27+2.38S$
Women.				
Original series	66	$C=+\ 13.78+0.89S$	68	$O=+\ 69.99+0.77S$
Supplementary series	35	$C=-\ 4.10+1.02S$	35	$O=-\ 62.07+1.56S$
Both series	101	$C=+\ 7.60+0.94S$	103	$O=+\ 29.93+1.01S$

women oxygen consumption increases from about 0.75 to 1.50 c.c. for each centimeter of stature, whereas in men the values are 2 to 3 c.c. for each centimeter of stature. Comparable but somewhat lower values are found for CO_2 excretion.

Diagram 10 shows the mean oxygen consumption of men and

women of different statures. Comparable values for carbon-dioxide elimination are represented in diagram 11. The straight lines are given by the equations for total men and women in table 27.

Because of the relatively small numbers of individuals for statistical work, the medium value of the correlation between stature and gaseous exchange, and the wide variation in stature and gas volume, the means show great irregularity. The straight line probably represents the four sets of averages as well as any other single curve of a higher order. At least it does not seem worth while at the present time to try any other equation until further materials are available.

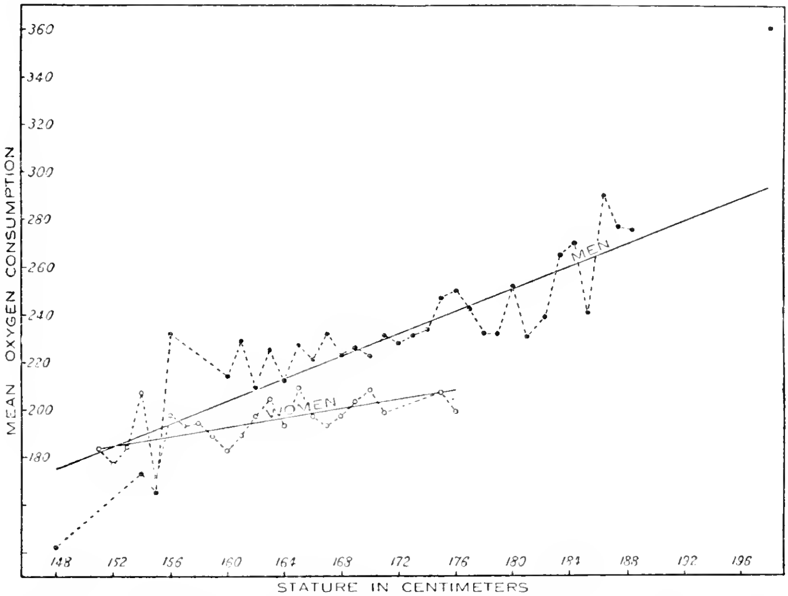

Diagram 10.—Mean oxygen consumption by men and women of various statures.

In this and the preceding sections we have shown that oxygen consumption and carbon-dioxide excretion are correlated with both body-weight and stature and have discussed the degree of the relationship. We now have to inquire whether the correlations between physical characters and gaseous exchange differ consistently in the case of the two gases. It might at first appear that these two values should be identical, but that the correlations between the physical characters and gaseous exchange would not necessarily be identical for the two gases is shown by the fact that the correlation between the two measures of gaseous exchange, while necessarily very high indeed, is not perfect. This point is brought out by the discussion of the correlation between oxygen consumption and carbon-dioxide production in Chapter III.

Turning to the question of the relative magnitude of the correlation between physical measurements and oxygen consumption and physical measurements and carbon-dioxide excretion, we may refer to the differences between the correlations for weight and the two gases as given in table 24 and for stature and the two gases as set forth in table 26.

The correlation for weight and gaseous exchange shows that, with an insignificant exception in the case of the total women, the relationship between body-weight and the amount of oxygen consumed is higher than that between body-weight and the quantity of carbon-dioxide eliminated. The same is true, with three exceptions only, in the lower correlations between stature and gaseous exchange.

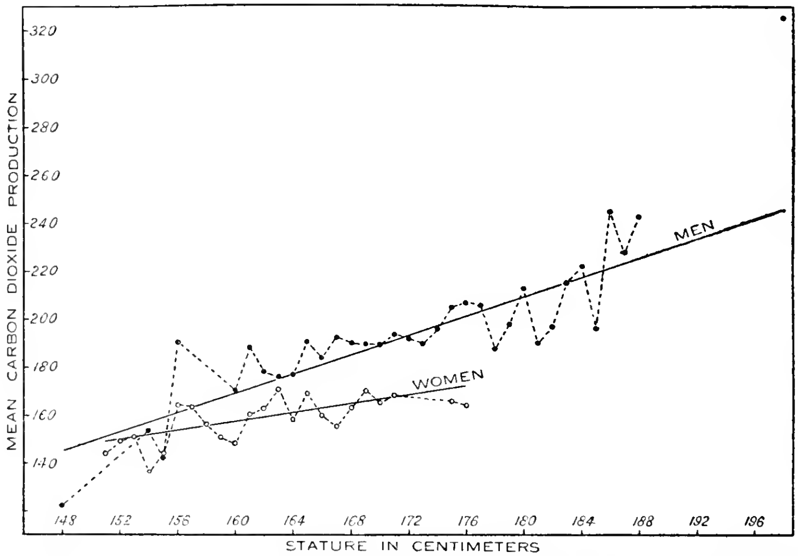

DIAGRAM 11.—Mean carbon-dioxide production by men and women of various statures.

The differences in correlations between body-weight and stature and the two gases are of a low order of magnitude, and because of the small number of individuals available can not be considered statistically significant for the individual series; but taking the data as a whole, there can be scarcely a doubt that the correlations between physical characters and oxygen consumption are significantly higher than those for physical characters and carbon-dioxide excretion.

In view of the fact that the total volume of oxygen consumed is not excreted as carbon dioxide, one might perhaps have expected the lower correlation between physical characters and gaseous exchange to be found for the gas which, considered alone, gives the minimum measure of the katabolic transformations occurring in the body. The same relationship has been shown to hold in the correlation between the volume of the two gases and pulse-rate discussed on page 78.

The second point of interest pertains to the problem of the relative magnitude of the correlations for weight and gaseous exchange and stature and gaseous exchange.

The differences between the correlations for stature and oxygen consumption and carbon-dioxide excretion, and body-weight and oxygen consumption and carbon-dioxide excretion are shown in table 28. With one single and numerically insignificant exception in the case of oxygen, the correlation between weight and gaseous exchange is higher than that between stature and gaseous exchange. A number of the differences are large enough in comparison with their probable errors to be looked upon as statistically significant.

TABLE 28.—*Comparison of correlations between weight and gaseous exchange and stature and gaseous exchange.*

Series.	N	Difference $r_{wo}-r_{so}$	Diff. / $E_{diff.}$	N	Difference $r_{wc}-r_{sc}$	Diff. / $E_{diff.}$
Men.						
Original series:						
Athletes	16	$+0.1797 \pm 0.0674$	2.67	15	$+0.1677 \pm 0.0747$	2.24
Others	62	$+0.1968 \pm 0.0872$	2.26	62	$+0.1911 \pm 0.0929$	2.06
Whole series	89	$+0.1944 \pm 0.0520$	3.74	88	$+0.1723 \pm 0.0542$	3.18
Gephart and Du Bois selection	72	$+0.1854 \pm 0.0597$	3.11	71	$+0.1971 \pm 0.0632$	3.12
First supplementary series	28	$+0.1747 \pm 0.0723$	2 42	28	$+0.0887 \pm 0.0762$	1.16
Orig'al and first supplementary series	117	$+0.1989 \pm 0.0437$	4.55	116	$+0.1747 \pm 0.0465$	3.76
Second supplementary series	19	-0.0061 ± 0.1449	0.04	19	$+0.0940 \pm 0.1729$	0.54
All men of three series	136	$+0.1815 \pm 0.0418$	4.34	135	$+0.1693 \pm 0.0453$	3.74
Women.						
Original series	68	$+0.5590 \pm 0.0865$	6.46	66	$+0.4916 \pm 0.0871$	5.64
Supplementary series	35	$+0.1401 \pm 0.1364$	1.03	35	$+0.1314 \pm 0.0140$	9.39
Both series	103	$+0.3619 \pm 0.0761$	4.76	101	$+0.3691 \pm 0.0748$	4.93

Body-mass is, therefore, a more important factor in determining (in the statistical but not necessarily in the causal sense) gaseous exchange than is stature.

7. WEIGHT AND TOTAL HEAT-PRODUCTION.

That large individuals should produce absolutely more calories than small ones would seem a natural *a priori* assumption. Our problem at this moment is to determine how intimate is the relationship between body-mass and heat-production. Examining, first of all, the results for the series of infants we find:

For males	$N=51$	$r_{wh}=0.7520 \pm 0.0411$	$r/E_r=18.30$
For females	$N=43$	$r_{wh}=0.8081 \pm 0.0357$	$r/E_r=22.64$
Difference		0.0561 ± 0.0544	

Disregarding sex and treating boy and girl babies together, we have

$$r_{wh}=0.7833 \pm 0.0269 \qquad r/E_r=29.12$$

These results are larger than those for stature (length) and total heat, which are 0.1329 ± 0.0712 smaller for males, 0.0655 ± 0.0583 smaller for females, and 0.0985 ± 0.0457 smaller for male and female babies considered together.

The change in actual heat-production in calories per 24 hours for a variation of a kilogram in body-weight is shown by the regression equations, which are:

For males............. $h = 25.16 + 34.52\,w$
For females........... $h = 26.18 + 34.23\,w$

The results are in remarkably close agreement. In both male and female babies a difference of 100 grams in weight between two subjects would mean a probable difference of 3.4 calories in their daily heat-production. The results are represented graphically in diagram

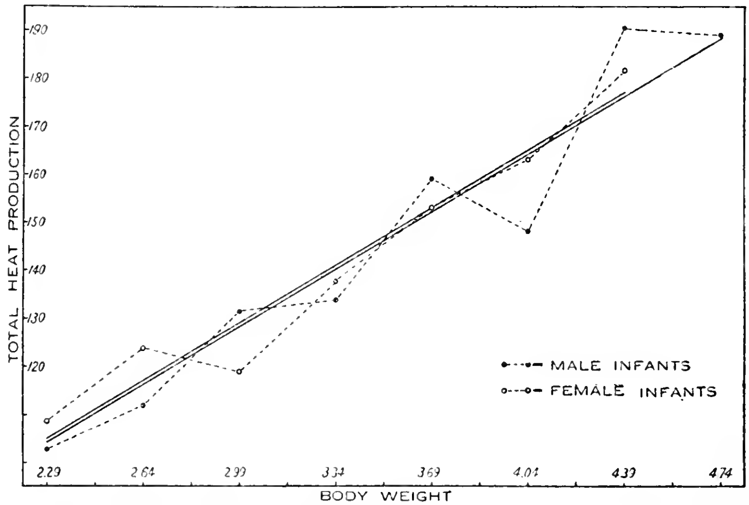

DIAGRAM 12.—Mean total daily heat-production by male and female infants of various body-weights.

12. The lines for the boy and girl babies lie very close together indeed. While the observed means show considerable irregularity, this is apparently attributable to the (statistically) small number of observations available, and a straight line seems to serve quite as well as a curve of a higher order to smooth the results.

Turn now to the available data for the adults. The correlations between body-weight and heat and the partial correlations between body-weight and heat-production for constant stature are set forth in table 29.

Considering first the actual correlations between body-weight and total heat-production, it is clear that the relationships are very high. For men they are of the order $r = 0.80$ in the larger series, although the

smaller subdivisions show fluctuations from $r=0.58$ for the 19 men of the second supplementary series to $r=0.96$ for the 16 athletes of the original series.

For women the results are somewhat lower. For the original series the correlation is $r=0.76$, a value in good accord with that for men, but the constant for the supplementary series is only $r=0.45$, a constant lower than the minimum relationship found in the several groupings of men. The low value in this supplementary series has the effect of reducing the measure of interdependence based on the original female series when the two are combined, with the resultant correlation of $r=0.61$ for the 103 women.

TABLE 29.—*Comparison of correlation between weight and total heat-production and partial correlation between weight and total heat-production with stature constant.*

Series.	N	Correlation between weight and heat-production r_{wh}	$\frac{r_{wh}}{E_{r_{wh}}}$	Partial correlation between weight and heat-production $_sr_{wh}$	$\frac{_sr_{wh}}{E_{_sr_{wh}}}$	Difference $_sr_{wh}-r_{wh}$
Men.						
Original series:						
Athletes	16	0.9577±0.0139	68.90	0.9259±0.0240	38.58	−0.0318
Others	62	0.6251±0.0522	11.98	0.5481±0.0599	9.15	−0.0770
Whole series	89	0.8012±0.0256	31.30	0.7105±0.0354	20.07	−0.0907
Gephart and Du Bois selection	72	0.7879±0.0301	26.18	0.6526±0.0456	14.31	−0.1353
First supplementary series	28	0.8664±0.0318	27.25	0.7196±0.0614	11.72	−0.1468
Original and first supplementary series	117	0.8175±0.0207	39.49	0.7192±0.0301	23.89	−0.0983
Second supplementary series	19	0.5758±0.1034	5.57	0.3609±0.1346	2.68	−0.2149
Other than Gephart and Du Bois selection	64	0.8022±0.0301	26.65	0.7177±0.0409	17.55	−0.0845
All men of three series	136	0.7960±0.0212	37.55	0.6867±0.0306	22.44	−0.1093
Women.						
Original series	68	0.7575±0.0349	21.71	0.7472±0.0361	20.70	−0.0103
Supplementary series	35	0.4536±0.0906	5.01	0.3556±0.0996	3.57	−0.0980
Both series	103	0.6092±0.0418	14.57	0.5803±0.0441	13.16	−0.0289

The nature of the relationship between body-weight and total heat-production is clearly brought out by diagram 13, which gives the average heat-productions for each weight grade for both men and women (total series) and the theoretical heat-productions due to the straight-line equations,

For total men. . . . . $N=136$ $h=617.493+15.824\,w$
For total women. . . . . $N=103$ $h=884.5276+8.227\,w$

Thus heat-production increases 15.8 calories for each kilogram of body-weight in the men and 8.2 calories for each kilogram of body-weight in the women.

The averages for the women are very irregular and apparently not well represented by a straight-line equation. The agreement of the empirical and the theoretical means in the case of the men is excellent for the groups containing a considerable number of subjects, *i.e.*, for those from 45 to 77 kilograms in weight.

We now turn to the partial correlations between weight and heat for constant stature. When we say we determine the correlation between body-weight and total heat-production for constant stature we mean that we determine from the whole material at our disposal, by the use of appropriate formulas, the correlation which would be found (within the limits of the probable errors of random sampling) if it were possible to sort our materials into groups of individuals of approximately like stature without so reducing the number of individuals in the groups as to render untrustworthy the correlation between weight and total heat-production.

The physical relationships involved in such determinations should be borne clearly in mind. If we determine the correlation between weight and total heat-production in individuals of constant height it is clear that the heavier individuals must be the "heavier set," plumper or fatter individuals.

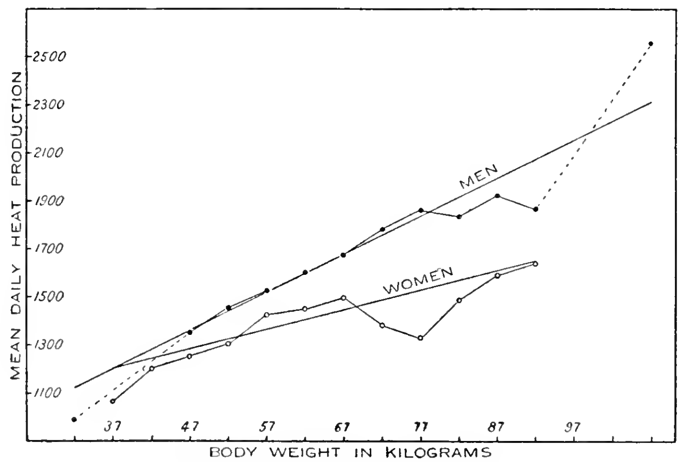

DIAGRAM 13.—Mean total daily heat-productions of adults, varying in body-weight.

Obtaining the partial correlations for weight and total heat per 24 hours for constant stature by

$$ {}_s r_{wh} = \frac{r_{wh} - r_{ws}\, r_{sh}}{\sqrt{1 - r_{ws}^2}\ \sqrt{1 - r_{sh}^2}} $$

we find the following values for infants:

	r_{wh}	${}_s r_{wh}$
For males	0.7520 ± 0.0411	0.5493 ± 0.0660
For females	0.8081 ± 0.0357	0.4937 ± 0.0778
For both	0.7833 ± 0.0269	0.5313 ± 0.0499

Correction for stature has very considerably reduced the correlation between body-weight and total heat-production. In the case of boy babies there is a reduction of 0.2027 or about 27 per cent, in the case

of the girl babies a reduction of 0.3144 or about 39 per cent, while if sex be disregarded the reduction is 0.2520 or about 32 per cent. The results indicate, however, that *the correlation is primarily due to body-mass rather than to body-length.*

The partial correlations for men and women are laid beside the gross correlations in table 29.

We note that without exception the correction for stature has reduced the correlation between weight and total heat-production. The amount of reduction is not, however, large. For the various series it is as follows:

	Percentage Reduction.
Men:	
Original series, $N=89$	11.3
Gephart and Du Bois selection, $N=72$	17.2
First supplementary series, $N=28$	16.9
Original and first supplementary series, $N=117$	12.0
Total men, $N=136$	13.7
Women:	
Original series, $N=68$	1.4
Supplementary series, $N=35$	21.6
Total women, $N=103$	4.7

The results which are based upon moderately large series of men are fairly regular. The smaller groups, of course, give much more variable percentages. The two series of women differ very greatly. The whole series of women seems to show a much smaller reduction in the correlation between weight and heat as a result of the correction for stature than do the total men. When more data are available, the detailed investigation of this point will be well worth while.

We now turn to the corrections for age in the adults. The results due to the formula

$$_{a}r_{wh}=\frac{r_{wh}-r_{ah}r_{aw}}{\sqrt{1-r_{ah}^{2}}\sqrt{1-r_{aw}^{2}}}$$

are laid beside the gross correlations in table 30. The results in this table are very striking. The partial correlations are, with the insignificant exception of the small series of athletes, larger than the original correlations uncorrected for age. Thus age heterogeneity has a measurable disturbing influence on the relationship between body-weight and total heat-production. When this influence is removed the closeness of correlation is increased.

Correcting for the influence of both age and stature, we have the partial correlations between weight and heat-production given by the formula

$$_{as}r_{wh}=\frac{r_{wh}(1-r_{as}^{2})-r_{aw}r_{ah}-r_{sw}r_{sh}+r_{as}(r_{aw}r_{sh}+r_{ah}r_{sw})}{\sqrt{(1-r_{as}^{2}-r_{sw}^{2}-r_{aw}^{2}+2r_{as}r_{aw}r_{sw})}\sqrt{(1-r_{as}^{2}-r_{sh}^{2}-r_{ah}^{2}+2r_{as}r_{ah}r_{sh})}}$$

These can be best understood if they are laid beside (1) the gross correlations between weight and heat, r_{wh}, beside (2) the correlations for weight and heat for constant stature and (3) the correlations between weight and heat for constant age. This is done in table 31.

TABLE 30.—*Comparison of correlations between weight and heat-production and between weight and heat-production for constant age.*

Series.	N	Correlation between weight and heat-production r_{wh}	Partial correlation between weight and heat-production $_ar_{wh}$	Difference $_ar_{wh}-r_{wh}$
Men.				
Original series:				
Athletes	16	0.9577±0.0139	0.9544±0.0150	−0.0033
Others	62	0.6251±0.0522	0.7032±0.0433	+0.0781
Whole series	89	0.8012±0.0256	0.8524±0.0196	+0.0512
Gephart and Du Bois selection	72	0.7879±0.0301	0.7983±0.0288	+0.0104
First supplementary series	28	0.8664±0.0318	0.8955±0.0252	+0.0291
Original and first supplementary series	117	0.8175±0.0207	0.8624±0.0160	+0.0449
Second supplementary series	19	0.5758±0.1034	0.6009±0.0989	+0.0251
Other than Gephart and Du Bois selection	64	0.8022±0.0301	0.8583±0.0222	+0.0561
All men of three series	136	0.7960±0.0212	0.8384±0.0172	+0.0424
Women				
Original series	68	0.7575±0.0349	0.7776±0.0323	+0.0201
Supplementary series	35	0.4536±0.0906	0.6040±0.0724	+0.1504
Both series	103	0.6092±0.0418	0.7117±0.0328	+0.1025

We note that in all cases correction for age and stature has decreased the values of the correlations between weight and heat-production in men but increased the constants measuring the relationship in women. Thus correction for two of the disturbing factors in the relationship between weight and heat-production has tended to bring the results obtained for the two sexes into closer agreement. For the total series the differences between the gross and the partial correlations are:

	Gross r_{wh}.	*Partial* $_{as}r_{wh}$.
Men	0.7960±0.0212	0.7510±0.0252
Women	0.6092±0.0418	0.6866±0.0351
Difference	0.1868±0.0469	0.0644±0.0432

Thus the difference between men and women is 3 times as large before correction for the influence of stature and age has been made as it is after the influence of these two variables has been eliminated. The difference between the gross correlations in the two sexes is probably significant in comparison with its probable error. The difference between the correlations corrected for the influence of age and stature is probably not statistically significant.

Comparing the partial correlations for both age and stature constant with those for stature only and age only constant, we note that the

differences between them are not large. The addition of the correction for age to that for stature has not greatly influenced the measure of the degree of interdependence between weight and heat.

TABLE 31.—*Comparison of gross correlation between weight and total heat-production and partial correlations between weight and heat-production for constant stature, constant age, and constant stature and age.*

Series.	N	Gross correlation for weight and heat-production r_{wh}	Correlation corrected for the influence of stature ${}_sr_{wh}$	Correlation corrected for the influence of age ${}_ar_{wh}$	Correlation corrected for both stature and age ${}_{as}r_{wh}$
Men.					
Original series:					
Gephart and Du Bois selection	72	0.7879±0.0301	0.6526±0.0456	0.7983±0.0288	0.6385±0.0471
Other than Gephart and Du Bois selection	64	0.8022±0.0301	0.7177±0.0409	0.8583±0.0222	0.7942±0.0311
All men of three series	136	0.7960±0.0212	0.6867±0.0306	0.8384±0.0172	0.7510±0.0252
Women.					
Original series	68	0.7575±0.0349	0.7472±0.0361	0.7776±0.0323	0.7674±0.0336
Supplementary series	35	0.4536±0.0906	0.3556±0.0996	0.6040±0.0724	0.5197±0.0832
Both series	103	0.6092±0.0418	0.5803±0.0441	0.7117±0.0328	0.6866±0.0351

8. STATURE AND TOTAL HEAT-PRODUCTION.

In infants the correlation between stature (length) and total heat produced is fairly high. The results are:

For males	$N=51$	$r_{sh}=0.6191\pm0.0582$	$r/E_r=11.22$
For females	$N=43$	$r_{sh}=0.7426\pm0.0461$	$r/E_r=16.11$
Difference		0.1235 ± 0.0719	

Both constants are unquestionably significant. That for females is somewhat higher than that for males. In comparison with its probable error the difference can not, however, be considered significant. Disregarding sex the correlation for the 94 babies is:

$$r_{sh}=0.6848\pm0.0369 \qquad r/E_r=18.56$$

Expressing these results in terms of actual change in total heat-production with differences in stature we have the following equations

For males.............. $h=-229.58+7.34\,s$
For females............ $h=-252.55+7.83\,s$

which are represented graphically in diagram 14.

The excellent agreement of the results for the two sexes is shown by the close parallelism of the two lines. While the observed means are very irregular because of the limited number of individuals, these straight lines serve fairly well to represent them, and until further data are available it is not worth while to try equations other than the linear.

For the various adult series the correlations between stature and total heat appear in table 32.

The constants for adults are positive throughout, indicating greater total heat-production by taller individuals.

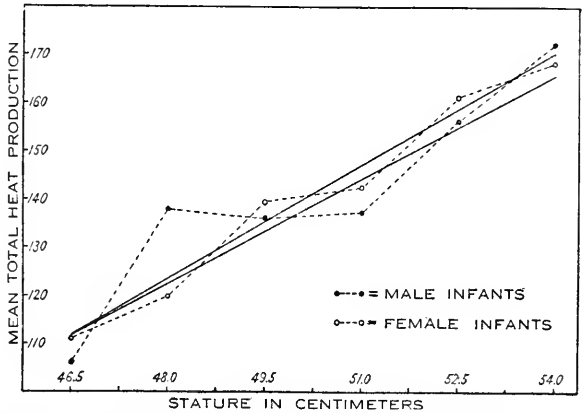

DIAGRAM 14.—Mean total daily heat-production of infants classified according to stature.

In the men the correlations are of the order $r = 0.60$. Because of the smallness of the groups of individuals—and possibly also for biological reasons—the constants for the subseries fluctuate between

TABLE 32.—*Comparison of correlation between stature and total heat-production with the correlation between weight and total heat-production.*

Series.	N	Correlation between stature and heat-production r_{sh}	Correlation between weight and heat-production r_{wh}	Difference $r_{wh} - r_{sh}$	$\frac{\text{Diff.}}{E_{diff.}}$
Men.					
Original series:					
Athletes	16	0.7861 ± 0.0644	0.9577 ± 0.0139	+0.1716 ± 0.0659	2.60
Others	62	0.4261 ± 0.0701	0.6251 ± 0.0522	+0.1990 ± 0.0874	2.28
Whole series	89	0.6098 ± 0.0449	0.8012 ± 0.0256	+0.1914 ± 0.0517	3.70
Gephart and Du Bois selection	72	0.5966 ± 0.0512	0.7879 ± 0.0301	+0.1913 ± 0.0594	3.22
First supplementary series	28	0.7071 ± 0.0637	0.8664 ± 0.0318	+0.1593 ± 0.0712	2.24
Original and first supplementary series	117	0.6218 ± 0.0382	0.8175 ± 0.0207	+0.1957 ± 0.0434	4.51
Second supplementary series	19	0.5589 ± 0.1064	0.5758 ± 0.1034	+0.0169 ± 0.1077	0.16
Other than Gephart and Du Bois selection	64	0.6290 ± 0.0510	0.8022 ± 0.0301	+0.1732 ± 0.0592	2.93
All men of three series	136	0.6149 ± 0.0360	0.7960 ± 0.0212	+0.1811 ± 0.0418	4.33
Women.					
Original series	68	0.1913 ± 0.0788	0.7575 ± 0.0349	+0.5662 ± 0.0862	6.57
Supplementary series	35	0.3139 ± 0.1028	0.4536 ± 0.0906	+0.1397 ± 0.1370	1.02
Both series	103	0.2318 ± 0.0629	0.6092 ± 0.0418	+0.3774 ± 0.0755	4.99

$r = 0.43$ for the 62 non-athletic and non-vegetarian individuals of the original series, and $r = 0.79$ for the 16 athletes. For the larger series, the values are in very good agreement indeed, considering them in comparison with their probable errors.

The women show correlations which differ remarkably from those found in the men. The original series is characterized by a correlation of only $r=0.19$, the supplementary series by a correlation of only $r=0.31$, and the total series by a correlation of $r=0.23$.

Comparing the total available materials for adult men and women, we find the following correlations and their difference:

For 136 men	$r_{sh}=0.6149\pm0.0360$
For 103 women	$r_{sh}=0.2318\pm0.0629$
Difference	0.3831 ± 0.0725

The difference is over 5 times as large as its probable error and certainly suggests a significant difference in the correlation between

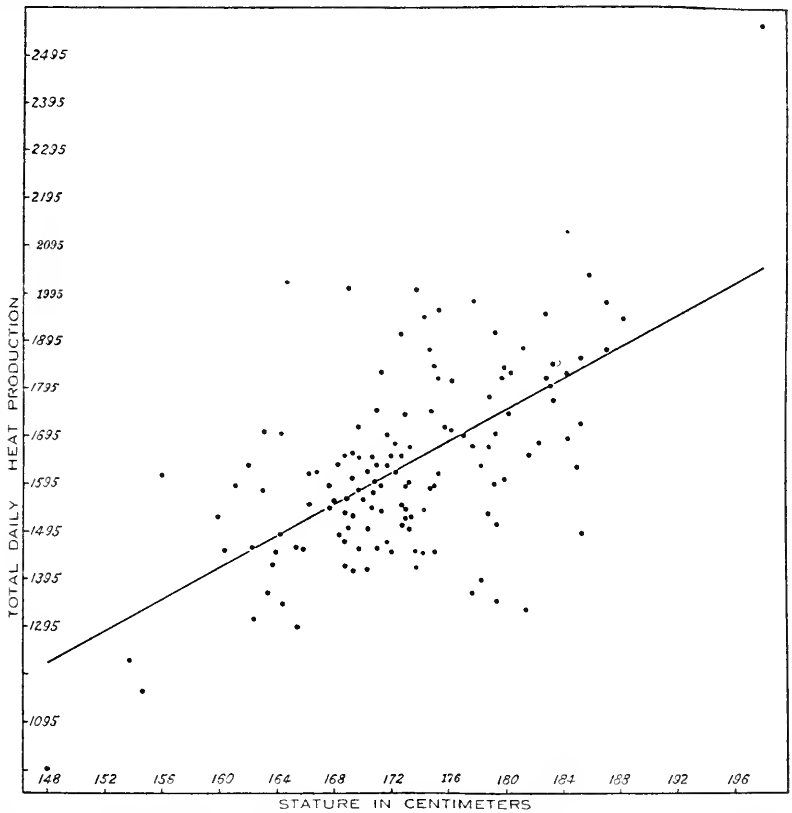

DIAGRAM 15.—Distribution of total daily heat-productions of men of various statures.

stature and total heat-production in men and women. Against the conclusion that this is a real sexual differentiation, may be possibly urged the fact (demonstrated immediately above) that in the infants the correlations are of about the same magnitude, the constant for girl babies being, as a matter of fact, slightly greater than that for boy babies.

The results for the relationship between stature and total heat in the two sexes may be conveniently compared in diagram 15 for men and 16 for women. The straight-line equations are:

For men................ $h = -1237.637 + 16.589\,s$
For women............ $h = 226.585 + 6.931\,s$

Thus heat-production increases about 16.6 calories per day in men and 6.9 calories per day in women for each variation of 1 cm. in stature. The constant term fixes the position of these lines when represented graphically. The averages represented in diagram 17 show that the heat-productions for men are regularly higher than those for women of the same stature. There is a strong suggestion of non-linearity in the case of the averages for men, but the numbers of individuals in the classes, especially the very tall and the very short individuals, is so small that detailed mathematical analysis seems unprofitable at present.

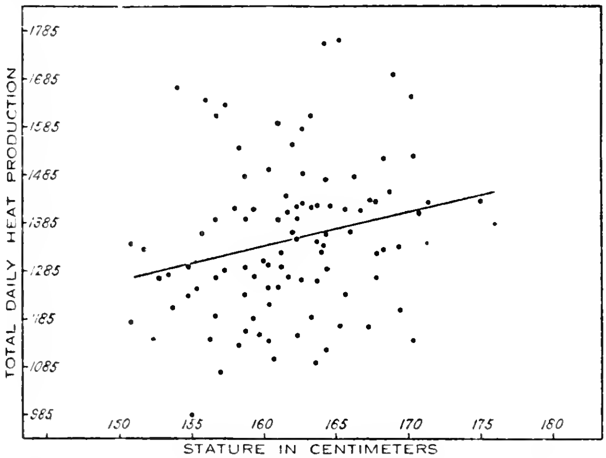

DIAGRAM 16.—Distribution of total daily heat-productions of women of various statures.

We have now to consider the problem of the relative magnitude of the correlations for body-weight and total heat-production and stature and total heat-production. Total heat is correlated with weight somewhat more closely than with stature in both males and females. The differences for infants are:

	Stature and total heat.	*Weight and total heat.*	*Difference in correlation.*
Males..........................	0.6191 ± 0.0582	0.7520 ± 0.0411	0.1329 ± 0.0712
Females.......................	0.7426 ± 0.0461	0.8081 ± 0.0357	0.0655 ± 0.0583
Difference.....................	0.1235 ± 0.0719	0.0561 ± 0.0544	
Both sexes....................	0.6848 ± 0.0369	0.7833 ± 0.0269	0.0985 ± 0.0457

On the basis of the present data for infants the differences in the correlations can not be considered statistically significant.

The more extensive data for adults also consistently show higher correlations between weight and total heat than between stature and

total heat. The actual differences and their probable errors appear in table 32. The correlations are consistent throughout in indicating a more intimate relation between body-weight and total heat-production than between stature and total heat-production. Notwithstanding the (statistically) few individuals considered, a number of the differences may be looked upon as individually significant in comparison with their probable errors.

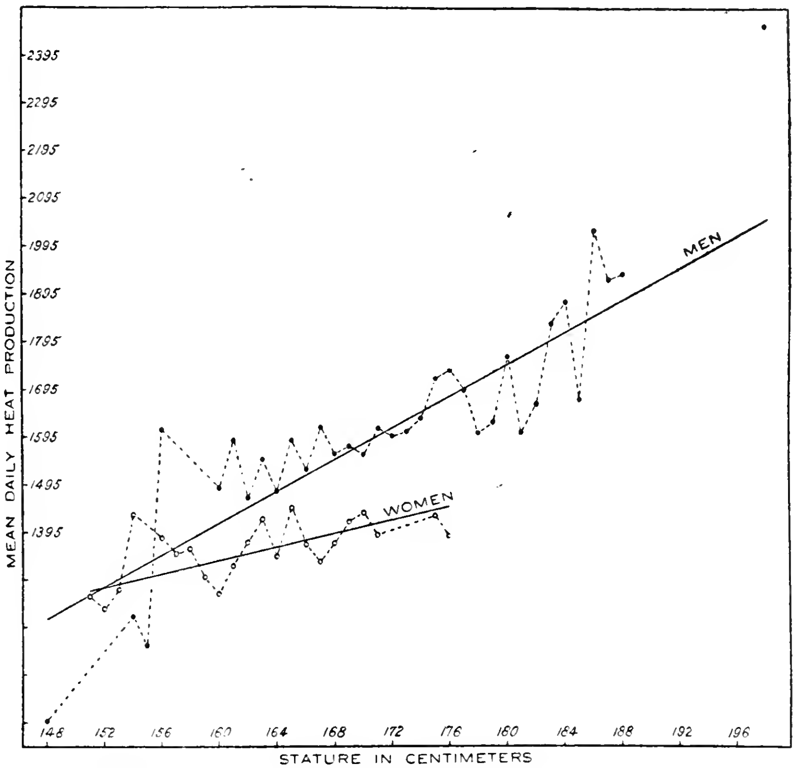

DIAGRAM 17.—Mean daily heat-production of normal men and women of various statures.

The differences in correlation vary considerably from series to series, ranging from 0.017 ± 0.108 in the 19 men of the second supplementary series to 0.566 ± 0.086 in the original women. We note, however, that the probable error is so high in the case of the second supplementary series of men that it can not really be asserted to differ significantly from the other groups of men. The larger groups of men show a difference of the order $r_{wh} - r_{sh} = 0.19$. In the women the differences are much larger because of the very low correlations between stature and total heat-production.

In the preceding section we considered the influence of age on the correlation between body-weight and total heat-production. It now

seems desirable to eliminate the possible influence of age upon the correlations between stature and total heat-production by using the partial correlation formula

$$_ar_{sh} = \frac{r_{sh} - r_{sa} r_{ah}}{\sqrt{1-r_{sa}^2}\ \sqrt{1-r_{ah}^2}}$$

With such low correlations as those which have been demonstrated between age and stature in Chapter III, the correction due to the correlation between age and stature will be small.

TABLE 33.—*Correlation between stature and total heat-production and partial correlation between stature and total heat-production with age constant.*

Series.	N	Correlation between stature and heat r_{sh}	$\frac{r_{sh}}{E_{r_{sh}}}$	Partial correlation between stature and heat $_ar_{sh}$	$\frac{_ar_{sh}}{E_{_ar_{sh}}}$	Difference $_ar_{sh} - r_{sh}$
Men.						
Original series:						
Athletes	16	0.7861±0.0644	12.21	0.7324±0.0782	9.37	−0.0537
Others	62	0.4261±0.0701	6.08	0.4397±0.0691	6.36	+0.0136
Whole series	89	0.6098±0.0449	13.58	0.5977±0.0460	12.99	−0.0121
Gephart and Du Bois selection	72	0.5966±0.0512	11.65	0.6542±0.0455	14.38	+0.0576
First supplementary series	28	0.7071±0.0637	11.10	0.7175±0.0618	11.61	+0.0104
Original and first supplementary series	117	0.6218±0.0383	16.24	0.6175±0.0386	16.00	−0.0043
Second supplementary series	19	0.5590±0.1064	5.25	0.5608±0.1061	5.29	+0.0018
Other than Gephart and Du Bois selection	64	0.6290±0.0510	12.33	0.6093±0.0530	11.49	−0.0197
All men of three series	136	0.6149±0.0360	17.08	0.6129±0.0361	16.98	−0.0020
Women.						
Original series	68	0.1913±0.0788	2.43	0.2196±0.0778	2.82	+0.0283
Supplementary series	35	0.3139±0.1028	3.05	0.3737±0.0981	3.81	+0.0598
Both series	103	0.2318±0.0629	3.69	0.2700±0.0616	4.38	+0.0382

The results are laid beside the gross correlations in table 33. In the larger series of data the differences between the gross correlations and the partial correlations are in no case as large as their probable errors. The disturbing influence of age upon the correlation between stature and total heat-production is, therefore, insignificant.

Since stature and body-weight are known to be correlated characters (see Chapter III), it is clear that the correlation between stature and total heat-production might be merely the resultant of the correlation between weight and heat-production and weight and stature. The fact that the correlation between stature and total heat-production is consistently lower than that between weight and total heat-production would, superficially considered, seem to support this view.

To test the question critically we must have recourse to the partial correlation coefficient between stature and heat-production for constant body-weight. Inserting the values of the correlation coefficients for stature and heat, weight and heat, and stature and weight in the

partial correlation formula for stature and total heat for constant weight,

$$_{w}r_{sh} = \frac{r_{sh} - r_{ws} r_{wh}}{\sqrt{1 - r_{ws}^2}\sqrt{1 - r_{wh}^2}}$$

we find for the infants:

	r_{sh}	$_{w}r_{sh}$
For males	0.6191 ± 0.0582	0.0949 ± 0.0936
For females	0.7426 ± 0.0461	0.1492 ± 0.1006

If sex be disregarded, we have:

$$r_{sh} = 0.6848 \pm 0.0369 \qquad _{w}r_{sh} = 0.1178 \pm 0.0686$$

In comparison with their probable errors the partial correlations are sensibly 0. All three are, however, positive in sign. Correction for body-weight has almost *but apparently not entirely* wiped out the relationship between stature and total heat-production.

For adults the results of the gross correlations and the partial correlations have been presented in table 34.

TABLE 34.—*Correlation between stature and total heat-production and partial correlation between stature and total heat-production with weight constant.*

Series.	N	Correlation between stature and total heat-production r_{sh}	$\frac{r_{sh}}{E_{r_{sh}}}$	Partial correlation between stature and total heat-production $_{w}r_{sh}$	$\frac{_{w}r_{sh}}{E_{_{w}r_{sh}}}$	Difference $_{w}r_{sh} - r_{sh}$
Men.						
Original series:						
Athletes	16	0.7861 ± 0.0644	12.21	0.5851 ± 0.1109	5.28	−0.2010
Others	62	0.4261 ± 0.0701	6.08	0.2453 ± 0.0805	3.05	−0.1808
Whole series	89	0.6098 ± 0.0449	13.58	0.3623 ± 0.0621	5.83	−0.2475
Gephart and Du Bois selection	72	0.5966 ± 0.0512	11.65	0.1573 ± 0.0775	2.03	−0.4393
First supplementary series	28	0.7071 ± 0.0637	11.10	0.1827 ± 0.1232	1.48	−0.5244
Original and first supplementary series	117	0.6218 ± 0.0382	16.28	0.3275 ± 0.0557	5.88	−0.2943
Second supplementary series	19	0.5589 ± 0.1064	5.25	0.3246 ± 0.1384	2.35	−0.2343
All men of three series	136	0.6149 ± 0.0360	17.08	0.3207 ± 0.0519	6.18	−0.2942
Women.						
Original series	68	0.1913 ± 0.0788	2.43	0.0397 ± 0.0817	0.49	−0.1516
Supplementary series	35	0.3139 ± 0.1028	3.05	0.0927 ± 0.1130	0.82	−0.2212
Both series	103	0.2318 ± 0.0629	3.69	0.0445 ± 0.0663	0.67	−0.1873

It is clear that in every series the correlation between stature and total heat-production is reduced when correction is made for body weight. The partial correlation between stature and heat for constant weight is not on the average zero. Instead, we have fairly substantial positive values throughout. Some of the constants taken individually may very reasonably be considered significant in comparison with their probable errors. The actual magnitude is of the order $_{w}r_{sh} = 0.30$ in the larger series of men, although the first supplementary series gives only $_{w}r_{sh} = 0.18$ and the Gephart and Du Bois selection gives $_{w}r_{sh} = 0.16$. The women seem to differ from the men and to agree with the infants

in indicating that correction for weight has practically, but not entirely, eliminated the correlation between stature and heat-production.

As a result of the analysis in this and the preceding section, we have shown that the correlation between weight and total heat-production is appreciably lowered when the factor of stature is eliminated by the use of the partial correlation coefficient and that the correlation between stature and metabolism is considerably reduced when the factor of body-weight is eliminated in a similar manner; but in neither case does the correlation disappear. Thus there is a relationship between weight and metabolism which is independent of stature, also a relationship between stature and metabolism which is independent of weight. These partial, residual, or net correlations, however one cares to designate them, are of a positive character. In other words, if a group of individuals of identical weight be examined the taller individuals will be found to have the higher metabolism. If a group of individuals of the same stature be examined, the heavier individuals will be found to have the greater metabolism.

It is evident that our partial correlations have a direct bearing on the problem of the metabolism of fat and lean individuals, a subject which has received considerable discussion in the literature of basal metabolism. If individuals of the same body-weight be classified according to stature, the taller individuals will necessarily be thinner than the shorter ones. The partial correlations show that in a given weight class the taller individuals have the greater gaseous exchange. In a group of individuals of identical weight, slenderness or spareness of build can result only from reduction in weight of bone, muscle, or fat. Reduction in fat mass seems the most probable source of an increase of stature without alteration in weight. We conclude, therefore, that the leaner individuals are those showing the higher metabolism. The partial or residual correlation is not in this case large.

In turning to the data which show that within a group of individuals of the same stature the heavier individuals show the higher heat-production, the reader may believe he sees a contradiction to the conclusion that the leaner individuals are those showing the higher metabolism. But such does not, on closer analysis, seem to be the case. In a group of individuals of the same stature, differences in body-weight may be due to fat, which in the main is inert in its direct contribution to metabolism, or they may be due to differences in the mass of muscular and other active tissues. Thus there is no incompatibility whatever in the statements that within a group of individuals of the same weight the *taller* have the greater metabolism, whereas in a group of the same stature the *thicker* individuals show the greater metabolism.

The recent investigation of Armsby and Fries,[1] in which they demonstrated a disproportionately high heat-production in a fat as

[1] Armsby and Fries, Journ. Agr. Res., 1918, 11, p. 451.

compared with a lean period in a steer does not seem to invalidate the conclusion that human individuals who are relatively tall for their weight have a higher metabolism than shorter ones. In the case of the fattening experiment reported by Armsby and Fries the *experimentally induced* changes in the nutritional level of the animal were brought about with relatively great rapidity. Concomitant with the fattening there was an increase of 36 per cent in the basal katabolism, just as in the case of a man undergoing a 31-day fast at the Nutrition Laboratory there was a 28 per cent decrease in the basal katabolism.[2] Without further evidence one would not be warranted in assuming that like differences would necessarily be found between different individuals of relatively permanent lean and fat physical constitution.

More recent investigations have shown that the basal metabolism of the human subject is profoundly affected by sudden modifications of the nutritional level, particularly those which are accompanied by rapid reduction in body-weight. If the food-intake be reduced below the maintenance level it is plain that with constant basal requirements there must be draft upon previously stored body-reserves.

Experiments with human subjects along this line demand a high degree of personal integrity and veracity on the part of the subjects. Such requirements were fulfilled by two squads of 12 men each from the International Y. M. C. A. College at Springfield, Massachusetts.[3] The first squad was kept for a period of 4 months upon a much restricted diet with an energy content of approximately one-half to two-thirds of the caloric requirements prior to the test. During the first few weeks there was a pronounced decrease in body-weight. After the body-weight had fallen on the average 12 per cent, an increase in the diet was made to prevent further loss in weight. Measurements of the groups as a whole in the large respiration chamber at the Nutrition Laboratory in which the 12 men slept every alternate Saturday night gave the basal metabolism during deep sleep.

The normal demand of the men prior to the reduction in diet ranged from 3200 to 3600 net calories. After a decrease of 12 per cent in weight only 1950 calories were required to maintain this weight.

The heat output as measured by indirect calorimetry and on the basis of calories per kilogram of body-weight and calories per square meter of body-surface was essentially 18 per cent lower than at the beginning of the study. Throughout the period of loss in weight and for some time following there was a marked loss of nitrogen. In round numbers these men lost approximately 150 grams of nitrogen. The nitrogen output per day at the maintenance diet of 1950 net calories

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[2] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915. Also Am. J. Physiol., 1916, **41**, p. 292.

[3] Benedict; Proc. Amer. Phil. Soc., 1918, **57**, p. 479. Also Benedict and Roth, Proc. Nat. Acad. Sci., 1918, **4**, p. 149. Also Benedict, Roth, Miles, and Smith, Carnegie Inst. Wash. Pub. 280. (In press).

was about 10.5 as compared with 14 grams in a control group with unrestricted diet.

This lowering of the metabolism accompanying the assumption of a thinner build is apparently opposed to the conclusions drawn above, according to which thinner individuals show a higher metabolism. Apparently, however, we have here, as in the fattening experiments of Armsby and Fries and in the prolonged fast of 31 days, to do with the special factor of rapid experimentally induced changes in the nutritional level of the organism, and not with the relatively permanent differences between fat and lean individuals.

Determining the partial correlation between stature and total heat-production in calories per day for constant body-weight and constant age by the formula

$$_{aw}r_{sh}=\frac{r_{sh}(1-r_{aw}^2)-r_{as}r_{ah}-r_{ws}r_{wh}+r_{aw}(r_{as}r_{wh}+r_{ah}r_{ws})}{\sqrt{(1-r_{aw}^2-r_{ws}^2-r_{as}^2+2r_{aw}r_{as}r_{ws})}\sqrt{(1-r_{wa}^2-r_{wh}^2-r_{ah}^2+2r_{aw}r_{ah}r_{wh})}}$$

and comparing the results with the gross correlations, r_{sh} and the correlation corrected for weight, $_wr_{sh}$, and for age, $_ar_{sh}$, we have the results in table 35.

TABLE 35.—*Comparison of gross correlation between stature and total heat-production and partial correlations between stature and heat-production for constant weight, for constant age, and for constant age and weight.*

Series.	N	Gross correlation between stature and heat-production r_{sh}	Correlation corrected for influence of weight $_wr_{sh}$	Correlation corrected for influence of age $_ar_{sh}$	Correlation corrected for both age and weight $_{aw}r_{sh}$
Men.					
Original series:					
Gephart and Du Bois selection	72	0.5966±0.0512	0.1573±0.0775	0.6542±0.0455	0.2561±0.0743
Other than Gephart and Du Bois selection	64	0.6290±0.0510	0.4220±0.0693	0.6093±0.0530	0.3442±0.0743
All men of three series	136	0.6149±0.0360	0.3207±0.0519	0.6129±0.0361	0.2899±0.0530
Women.					
Original series	68	0.1913±0.0788	0.0397±0.0817	0.2196±0.0778	0.0784±0.0813
Supplementary series	35	0.3139±0.1028	0.0927±0.1130	0.3737±0.0981	0.1064±0.1127
Both series	103	0.2318±0.0629	0.0445±0.0663	0.2700±0.0616	0.0850±0.0660

The correlations for stature and heat-production are positive throughout, even after correction has been made for both age and weight. This fully substantiates the conclusion drawn above concerning the existence of an independent physiological relationship between stature and heat-production. The partial correlations for both age and weight constant are in some cases higher and in some cases lower than those in which weight only is corrected for. This shows the relatively small influence of age on the correlation between stature and heat-production. This influence is small, not because there is no relationship

between age and metabolism, but because in adults there is little relationship between age and stature.

9. RECAPITULATION AND DISCUSSION.

1. Our series of data show practically no relationship between basal or minimum pulse-rate and body-weight in adults. In new-born infants there may be a slight positive correlation, more rapid pulse being associated with greater body-weight, but further investigation is necessary before final conclusions can be drawn.

2. As far as our data show, there is practically no relationship between stature and pulse-rate in man.[4]

3. There is a low but significant positive correlation between minimum pulse-rate and gaseous exchange in men, larger gaseous exchange being associated with more rapid pulse-rate. The series of women available show as yet inexplicable inconsistencies in these relationships. The correlation between pulse-rate and oxygen consumption is more intimate than that between pulse-rate and carbon-dioxide excretion. Physiologists have long been familiar with the correlation between pulse-rate and metabolism in the same individual, that is with the intra-individual correlation between the rate of the heart-beat and the amount of the katabolism. Here, however, we are dealing with the problem of the relationship between the minimum pulse-rates of a series of individuals and their basal metabolism constants—that is, with inter-individual correlation.

4. The inter-individual correlations between pulse-rate and gross heat-production are positive throughout, but low and variable in magnitude. When correction for body-size is made by expressing heat production in calories per kilogram of body-weight or in calories per square meter of body-surface, the magnitude of the correlations is materially raised. This indicates that the relationship is one of real physiological significance. The most intimate correlations are obtained when correction for body-size is made by expressing heat-production in calories per square meter of body-surface. This result has an obvious bearing on the so-called body-surface law, to be discussed in Chapter VI.

5. There is a high positive correlation between body-weight and gaseous exchange. The correlations are of the order $r = 0.75$ for men and $r = 0.60$ for women. Expressed in actual gaseous exchange, this degree of correlation means that in men oxygen consumption increases about 2.27 and carbon-dioxide excretion increases about 1.89 c.c. per minute for an increase of 1 kilogram of body-weight. For women the values are about 1.17 c.c. O_2 and 1.02 c.c. CO_2 per kilogram of weight. These are the values for the grand total series. Those for the several sub-series differ considerably among themselves.

[4] Conclusions 1 and 2 must be understood to be limited to our own data for minimum or basal pulse-rates. They may not be strictly valid for subjects under other conditions. This question may be treated by one of us later.

6. There is a substantial correlation between stature and gaseous exchange. The correlations for men are of the order $r = 0.60$, while for women they are of the order $r = 0.30$. In terms of actual gas volume these coefficients show that oxygen consumption increases about 1 c.c. for each increase of 1 cm. in stature in the women, whereas in the men the increase is between 2 and 3 c.c. Comparable, but somewhat lower values are found for carbon-dioxide excretion.

7. The correlations between both stature and body-weight on the one hand and oxygen consumption on the other are higher than those between these two physical characters and carbon-dioxide excretion. Since the total volume of oxygen consumed is not excreted as carbon dioxide this result should have been expected.

8. Comparison of the correlations between body-weight and gaseous exchange and those between stature and gaseous exchange shows that the correlation between weight and gaseous exchange is higher than that between stature and gaseous exchange. Thus body-mass is a more important factor than is stature in determining (in the statistical but not necessarily in the causal sense) gaseous exchange.

9. The correlations between body-weight and total heat-production are high. Thus coefficients of the order $r = 0.75$ to $r = 0.80$ have been found for male and female new-born infants, of the order $r = 0.80$ in men and $r = 0.60$ in women. In terms of actual heat productions these correlations, taken in connection with the means and standard deviations, show that in the new-born infants a difference of 100 grams in body-weight implies a difference of about 3.4 calories in daily heat-production. In the adults a difference of one kilogram in body-weight is followed by an average difference of 8.2 calories in heat-production in women and 15.8 calories in men.

10. There is a significant positive correlation between stature (body-length) and total heat-production in both new-born infants and adults. The correlations are consistently lower than those for weight and total heat-production.

11. Since tall individuals are on the average heavy individuals, and since heavy individuals are on the average tall individuals, it has been necessary to inquire to what extent the correlation between total heat-production and stature is merely the statistical resultant of the correlations between weight and heat and stature and weight, and to inquire to what extent the correlation between weight and heat-production is merely the resultant of the correlation between stature and heat-production and between weight and stature. In proceeding in this way we have been treating the data in a purely objective manner, basing our treatment on no physiological theory concerning the relative importance of stature or weight in determining basal metabolism. Our results show that both stature and body-weight have independent significance in determining the basal metabolism of the normal individual.

CHAPTER V.

CHANGES IN METABOLISM WITH AGE.

The significance of a knowledge of the relationship of metabolism to age is twofold.

First, the change of normal basal metabolism with age is in and for itself a problem of prime physiological importance.

Second, metabolism determinations in the hospital ward have little value as a basis for medical theory or practice except as the constants are interpreted in comparison with those for normal controls. It is important, therefore, that in selecting controls for comparison with pathological cases the influence of the age factor in both health and disease should be fully known.

Our treatment in this place differs from that accorded the problem by earlier writers in that we have actually determined statistical constants measuring the rate of change in metabolism with age during the period of adult, or practically adult, life.

Ultimately it will be necessary to undertake an examination of the change of physical and physiological characters other than direct or indirect heat measurements as a first step towards a closer coördination of investigation in human metabolism and the results of general biological research. Such coördination should be to the advantage of both the special field of human nutrition and the broader field of general biological theory.

In this place we shall merely present, and statistically discuss, the available data for human basal metabolism in relation to age. A comparative examination of age changes in other physical and physiological characters must be reserved for the future.

1. HISTORICAL REVIEW.

It was of course inevitable that the problem of the dependence of metabolism on age should be considered in a general comparative way as soon as determinations of the basal metabolism of infants, youths, and adults began to be made.

While the observations of Andral and Gavarret [1] can not be taken as basal, we have determined the correlation between age and CO_2 production per hour in the men 17 to 102 years of age and in the women

[1] Andral and Gavarret, Ann. de chim. et phys., 1843, 8, 3 sér., p. 129.

19 to 82 years of age, using the constants as tabled by Sondén and Tigerstedt.[2]

We find:

For men	..... $N = 29$	$r_{ah} = -0.629 \pm 0.076$
For women	.... $N = 17$	$r_{ah} = -0.058 \pm 0.163$

Both coefficients are negative, suggesting a decrease in gaseous exchange with age; that for men is large.

Most unfortunately statures and weights of these individuals are not given. It is not possible, therefore, to correct for these factors which are later shown to have a large disturbing influence on the measure of the relationship between age and metabolism. In view of this fact, and that the constants for the individual subjects may show a considerable variation due to their not being truly basal, and further that the number of individuals is small, better agreement with the results presented for our own series of subjects could perhaps not have been expected.

The classic work of Sondén and Tigerstedt themselves,[3] while discussing in a most exhaustive way many of the fundamental questions of metabolism, is based on observations made before the precautions necessary for basal determinations were understood.

Magnus-Levy and Falk,[4] in 1899, concluded that the basal metabolism is low in infancy, high in childhood, and low after the onset of old age. They considered it essentially constant during the period of adult life.

We have determined the correlations between age and calories per 24 hours, computed from the data of Magnus-Levy and Falk. We find:

	Correlation r_{ah}
In men, $N = 10$	-0.288 ± 0.201
In men and old men, $N = 13$	-0.481 ± 0.134
In women, $N = 14$	-0.576 ± 0.120
In women and old women, $N = 17$	-0.569 ± 0.111

Thus in both the men and women studied by Magnus-Levy and Falk heat-production is shown to decrease with age.

We may, of course, further investigate the relationship between age and heat-production in the series of Magnus-Levy and Falk by determining the partial correlation between age and heat-production for constant body-weight. The results are as follows:

	Partial Correlation $_{w}r_{ah}$
For men	-0.147 ± 0.209
For men and old men	-0.712 ± 0.088
For women	-0.210 ± 0.172
For women and old women	-0.727 ± 0.077

[2] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, pp. 55-56.

[3] Sondén and Tigerstedt, loc. cit.

[4] Magnus-Levy and Falk, Arch. f. Anat. u. Phys., Physiol. Abt., 1899, Suppl., p. 361.

Again the probable errors are high because of the small numbers of individuals studied. But one can hardly examine the results as a whole without reaching the conviction that Magnus-Levy and Falk were in error in concluding that metabolism remains essentially constant during adult life. Metabolism decreases throughout adult life, and this decrease is shown by the statistical analysis of their own data to be as evident after correction for the influence of body-size has been made as before.

Carbon-dioxide production in boys of 10 to 18 years of age has been investigated by Olin,[5] although not under strictly basal conditions.

One of the objects of the investigations which have been under way on human basal metabolism at the Nutrition Laboratory for a number of years has been the determination of the changes which take place in metabolism throughout the entire period of life. It was the intention to base this investigation upon a number of subjects sufficiently large to eliminate the influence of individual variations at different ages, and thus to obtain a smoothed curve of basal metabolism of both male and female individuals throughout the entire period of life. Before this program was complete Du Bois[6] combined the extensive data already published from the Nutrition Laboratory with fragmentary data from other sources and attempted to draw a curve of human basal metabolism for the entire period of life.

In our opinion the time is not yet ripe for an undertaking of such magnitude. While data are still being accumulated for this purpose, and while the results based on 136 men and 103 women are subject to revision as more extensive materials for the earlier and later periods of life are obtained, it seems desirable to analyze in a preliminary way the age changes in the subjects considered in this volume. Certain difficulties in the way of combining different series of measurements to secure a picture of the metabolic activity of the human subjects from birth to death will be indicated in Chapter VIII (p. 243).

2. STATISTICAL CONSTANTS MEASURING CHANGES IN METABOLISM WITH AGE.

The range of ages of the individuals in each class, and the statistical constants of age in years, in the several groups of subjects appear in table 36.

The constants showing the correlation between age and total heat-production in calories per 24 hours are given in table 37. Without exception the values of r_{ah} are negative in sign, thus indicating that in

[5] Olin, Finska läk.-sällsk. handl., Helsingfors, 1915, **57**, p. 1434. At the time of going to press the German report of this research, announced for appearance in the Skandinavisches Archiv für Physiologie, is not available and hence analysis of the data is unfortunately now impossible.

[6] Du Bois, Am. Journ. Med. Sci., 1918, **102**, p. 781. Also Med. Bull. Cornell Univ., 1917, **6**, pt. 2, p. 33.

groups of individuals of the age-range here under consideration total heat-production decreases with increasing age.

Nine of the 12 values are over 3 times as large as their probable errors. They are, however, extremely irregular in magnitude, ranging from -0.092 ± 0.126 in the first supplementary series of men ($N = 28$)

TABLE 36.—*Statistical constants of age in adults.*

Series.	N	Age range.	Average.	Standard deviation.	Coefficient of variation.
Men.					
Original series:					
Athletes	16	19–29	22.06 ± 0.45	2.66 ± 0.32	12.04 ± 1.46
Others	62	16–63	26.08 ± 0.64	7.51 ± 0.45	28.78 ± 1.88
Whole series	89	16–63	26.15 ± 0.56	7.86 ± 0.40	30.07 ± 1.97
Gephart and Du Bois selection	72	20–43	25.74 ± 0.44	5.57 ± 0.31	21.63 ± 1.27
First supplementary series	28	19–45	25.64 ± 0.71	5.56 ± 0.50	21.67 ± 2.04
Original and first supplementary series	117	16–63	26.03 ± 0.46	7.38 ± 0.33	28.36 ± 1.35
Second supplementary series	19	18–62	32.11 ± 2.09	13.53 ± 1.48	42.15 ± 5.37
Other than Gephart and Du Bois selection	64	16–63	28.16 ± 0.94	11.20 ± 0.67	39.77 ± 2.72
All men of three series	136	16–63	26.88 ± 0.51	8.77 ± 0.36	32.63 ± 1.47
Women.					
Original series	68	15–74	26.66 ± 0.81	9.88 ± 0.57	37.04 ± 2.42
Supplementary series	35	18–73	39.86 ± 1.82	15.97 ± 1.29	40.07 ± 3.71
Both series	103	15–74	31.15 ± 0.92	13.79 ± 0.65	44.27 ± 2.46

TABLE 37.—*Correlation between age and total heat-production and partial correlation between age and heat-production for constant stature and for constant body-weight.*

Series.	N	Gross correlation between age and heat-production r_{ah}	$\frac{r_{ah}}{E_{r_{ah}}}$	Correlation corrected for influence of weight ${}_wr_{ah}$	$\frac{{}_wr_{ah}}{E_{{}_wr_{ah}}}$	Correlation corrected for influence of stature ${}_sr_{ah}$	$\frac{{}_sr_{ah}}{E_{{}_sr_{ah}}}$
Men.							
Original series:							
Athletes	16	-0.4664 ± 0.1319	3.54	-0.3977 ± 0.1420	2.80	-0.2240 ± 0.1602	1.40
Others	62	-0.1292 ± 0.0842	1.53	-0.4290 ± 0.0699	6.14	-0.1756 ± 0.0830	2.12
Whole series	89	-0.3529 ± 0.0626	5.64	-0.5756 ± 0.0478	12.04	-0.3227 ± 0.0641	5.03
Gephart and Du Bois selection	72	-0.3716 ± 0.0685	5.42	-0.4192 ± 0.0655	6.40	-0.4842 ± 0.0609	7.95
First supplementary series	28	-0.0917 ± 0.1264	0.73	-0.4609 ± 0.1004	4.59	-0.1942 ± 0.1227	1.58
Original and first supplementary series	117	-0.2954 ± 0.0569	5.19	-0.5428 ± 0.0440	12.34	-0.2817 ± 0.0574	4.91
Second supplementary series	19	-0.5007 ± 0.1159	4.32	-0.5328 ± 0.1108	4.81	-0.5029 ± 0.1156	4.35
Other than Gephart and Du Bois selection	64	-0.3003 ± 0.0767	3.92	-0.5728 ± 0.0566	10.12	-0.2313 ± 0.0798	2.90
All men of three series	136	-0.3062 ± 0.0524	5.84	-0.5147 ± 0.0425	12.11	-0.3003 ± 0.0526	5.71
Women.							
Original series	68	-0.2322 ± 0.0774	3.00	-0.3499 ± 0.0718	4.87	-0.2556 ± 0.0764	3.35
Supplementary series	35	-0.1796 ± 0.1103	1.63	-0.4755 ± 0.0882	5.39	-0.2764 ± 0.1053	2.62
Both series	103	-0.2034 ± 0.0637	3.19	-0.4976 ± 0.0500	9.95	-0.2465 ± 0.0624	3.95

to -0.501 ± 0.116 in the second supplementary series ($N = 19$). While the probable errors of these constants are relatively very high because of the small numbers of individuals available, this need not be taken as the final explanation of the highly irregular values. Both stature and body-weight vary greatly in human individuals, and, as pointed out on page 63, this variation in the adult is largely independent of

age. But while age and body-weight and age and stature are very little correlated in adult life, stature and weight, especially the latter, are closely correlated with metabolism. Thus irregularities of stature or body-weight would tend to dilute the correlation between age and total heat-production.

The reader who has followed the lines of reasoning employed in preceding sections of this volume will at once suggest that there are two ways in which the influence of these disturbing factors can be eliminated. First, we may determine the partial correlation coefficients between age and total heat-production for constant stature and for constant body-weight. Second, we may make the corrections for the influence of body-weight or of both body-weight and stature by expressing metabolism in terms of calories per kilogram or calories per square meter of surface and subsequently correlate these heat-productions per standard unit with age. We have carried out the analysis by both methods.

Table 38.—*Correlation between age and heat-production per kilogram of body-weight and comparison with correlation between age and total heat-production.*

Series.	N	Correlation between age and total heat-production r_{ah}	$\frac{r_{ah}}{E_{r_{ah}}}$	Correlation between age and heat-production per kilogram r_{ah_k}	$\frac{r_{ah_k}}{E_{r_{ah_k}}}$	$r_{ah_k} - r_{ah}$
Men.						
Original series:						
Athletes	16	-0.4664 ± 0.1319	3.54	$+0.0439 \pm 0.1683$	0.26	$+0.5103$
Others	62	-0.1292 ± 0.0842	1.53	-0.4633 ± 0.0673	6.88	-0.3341
Whole series	89	-0.3529 ± 0.0626	5.64	-0.4208 ± 0.0588	7.16	-0.0679
Gephart and Du Bois selection	72	-0.3716 ± 0.0685	5.42	-0.2626 ± 0.0740	3.55	$+0.1090$
First supplementary series	28	-0.0917 ± 0.1264	0.73	-0.4629 ± 0.1002	4.62	-0.3712
Original and first supplementary series	117	-0.2954 ± 0.0569	5.19	-0.4275 ± 0.0510	8.38	-0.1321
Second supplementary series	19	-0.5007 ± 0.1159	4.32	-0.3885 ± 0.1314	2.96	$+0.1122$
Other than Gephart and Du Bois selection	64	-0.3003 ± 0.0767	3.92	-0.4791 ± 0.0650	7.37	-0.1788
All men of three series	136	-0.3062 ± 0.0524	5.84	-0.4078 ± 0.0482	8.46	-0.1016
Women.						
Original series	68	-0.2322 ± 0.0774	3.00	-0.1510 ± 0.0799	1.89	$+0.0812$
Supplementary series	35	-0.1796 ± 0.1103	1.63	-0.6533 ± 0.0653	10.00	-0.4737
Both series	103	-0.2034 ± 0.0637	3.19	-0.4931 ± 0.0503	9.80	-0.2897

The partial correlations between age and heat for constant body-weight,

$$ {}_w r_{ah} = \frac{r_{ah} - r_{aw} r_{wh}}{\sqrt{1 - r_{aw}^2}\ \sqrt{1 - r_{wh}^2}} $$

and the partial correlations between age and heat for constant stature,

$$ {}_s r_{ah} = \frac{r_{ah} - r_{as} r_{sh}}{\sqrt{1 - r_{as}^2}\ \sqrt{1 - r_{sh}^2}} $$

are laid beside the gross correlations in table 37. The correlation between age and heat-production per kilogram of body-weight is com-

pared with the gross correlation in table 38. The same comparison for heat-production per unit of body-surface is made in table 39.

The partial correlations for age and total heat-production for constant stature in table 37 show about the same irregularities as the gross correlations. The constants are sometimes lower and sometimes higher than the original coefficients. This failure of correction for stature to make a large difference in the correlations between age and heat-production is to be expected because of the relative laxness of the correlation between stature and heat-production, as demonstrated on page 96.

TABLE 39.—*Correlation between age and heat-production per square meter of body-surface and comparison with correlation between age and total heat-production.*

Series.	N	Surface estimated, Meeh formula.		Surface estimated, Du Bois height-weight chart.		Difference $r_{ah_M}-r_{ah}$	Difference $r_{ah_D}-r_{ah}$
		r_{ah_M}	$\frac{r_{ah_M}}{E_{r_{ah_M}}}$	r_{ah_D}	$\frac{r_{ah_D}}{E_{r_{ah_D}}}$		
Men.							
Original series:							
Athletes............	16	−0.4537±0.1339	3.39	−0.4203±0.1388	3.03	+0.0127±0.1879	+0.0461±0.1916
Others............	62	−0.4817±0.0658	7.32	−0.4243±0.0702	6.04	−0.3525±0.1068	−0.2951±0.1095
Whole series.........	89	−0.5622±0.0489	11.50	−0.5253±0.0518	10.14	−0.2093±0.0794	−0.1724±0.0812
Gephart and Du Bois selection..........	72	−0.4124±0.0660	6.25	−0.4672±0.0621	7.52	−0.0408±0.0949	−0.0956±0.0922
First supplementary series..............	28	−0.4402±0.1028	4.28	−0.3498±0.1119	3.13	−0.3485±0.1628	−0.2581±0.1688
Original and first supplementary series.....	117	−0.5401±0.0442	12.22	−0.4819±0.0479	10.06	−0.2447±0.0721	−0.1865±0.0742
Second supplementary series..............	19	−0.4966±0.1166	4.26	−0.5203±0.1128	4.61	+0.0041±0.1643	−0.0196±0.1619
Other than Gephart and Du Bois selection.....	64	−0.5778±0.0562	10.28	−0.4986±0.0634	7.86	−0.2775±0.0949	−0.1983±0.0995
All men of three series..	136	−0.5111±0.0427	11.97	−0.4698±0.0451	10.42	−0.2049±0.0678	−0.1636±0.0693
Women.							
Original series.........	68	−0.2745±0.0756	3.63	−0.3547±0.0715	4.96	−0.0423±0.1082	−0.1225±0.1054
Supplementary series...	35	−0.6255±0.0694	9.01	−0.5637±0.0779	7.24	−0.4459±0.1304	−0.3843±0.1349
Both series...........	103	−0.5437±0.0468	11.62	−0.5238±0.0482	10.87	−0.3403±0.0787	−0.3204±0.0800

The case is quite different with the partial correlations for age and metabolism for constant weight. With one single exception, in which the difference is small, the constants for the relationship between age and heat corrected for the influence of body-weight are numerically larger than the uncorrected values. A careful study of these values shows how greatly correction for body-weight has smoothed the series of constants for the relationship between age and metabolism. They range from −0.350 to −0.576 when the two sexes are considered together, but when the probable errors are taken into account the constants can hardly be asserted to differ significantly among themselves. The larger series indicate the medium correlation of −0.5 between age and heat-production for constant weight.

Turning now to the correlations between age and heat-production per unit of body-weight and body-surface, we may compare the correlations between age and total heat-production with those between age and relative heat-production, *i. e.*, heat-production per kilogram of weight or per square meter of body-surface, in tables 38 and 39.

From table 38, in which the correlations between age and total heat-production are compared with those between age and heat per kilogram of body-weight, we note that in all cases except the athletes[7] heat per kilogram of weight is negatively correlated with age—that is *relative* heat-production as well as *total* heat-production decreases with age. In the larger series of men, with the exception of the Gephart and Du Bois selection and the second supplementary series, the correlation between age and relative heat-production is numerically larger than that between age and gross heat-production. This is also true in the supplementary series and in the grand total series of women. Thus variations in the size of the individuals as measured by weight tend to disturb to some extent the correlations between age and heat-production.

Turning now to the correction for differences in size resulting from the expression of heat-production in calories per square meter of body-surface we have the results set forth in table 39. *Without exception the 24 correlations are negative in sign. With three exceptions only*[8] the correlations between age and heat-production per square meter of body-surface are of a more strongly negative order than the correlations between age and total heat-production.

In determining the relationship between age and total heat-production, correction for the influence of both body-weight and stature may be made by the use of the partial correlation formula for two variables constant

$$ {}_{sw}r_{ah} = \frac{r_{ah}(1-r_{sw}^2) - r_{sa}r_{sh} - r_{wa}r_{wh} + r_{sw}(r_{sa}r_{wh} + r_{sh}r_{wa})}{\sqrt{(1-r_{sw}^2 - r_{wa}^2 - r_{sa}^2 + 2r_{sw}r_{sa}r_{wa})}\sqrt{(1-r_{sw}^2 - r_{wh}^2 - r_{sh}^2 + 2r_{sw}r_{sh}r_{wh})}} $$

Comparing the values of ${}_{sw}r_{ah}$ with the gross correlations, r_{ah}, and the partial correlations for stature and weight, ${}_{s}r_{ah}$ and ${}_{w}r_{ah}$, we have the results in table 40.

Correction for both stature and weight has not given constants very different from those in which the correlation is corrected for weight only.

Correction for both stature and weight has rendered the correlations between age and heat-production in the two sexes much more

[7] There are only 16 athletes. The age range is only 19-29 years, and the correlation is small in actual magnitude and only about one-fourth of its probable error.

[8] All of these exceptions are trivial in magnitude and only a fraction of their probable errors.

alike. Thus the differences between the correlations and partial correlations for the two sexes are:

	Correlation. r_{ah}	*Partial correlation.* $_{sw}r_{ah}$
Men	-0.3062 ± 0.0524	-0.4995 ± 0.0434
Women	-0.2034 ± 0.0637	-0.5016 ± 0.0497
	0.1028 ± 0.0825	0.0021 ± 0.0660

The fact that correction for stature and body-weight has made the constants sensibly identical gives us great confidence in the reality of the physiological law connecting age change and metabolism.

TABLE 40.—*Comparison of gross correlation between age and heat-production and partial correlation between age and heat-production for constant stature, constant weight, and constant stature and weight.*

Series.	N	Gross correlation between age and heat-production r_{ah}	Correlation corrected for influence of stature $_{s}r_{ah}$	Correlation corrected for influence of weight $_{w}r_{ah}$	Correlation corrected for influence of stature and weight $_{sw}r_{ah}$
Men.					
Original series:					
Gephart and Du Bois selection	72	-0.3716 ± 0.0685	-0.4842 ± 0.0609	-0.4192 ± 0.0655	-0.4585 ± 0.0628
Other than Gephart and Du Bois selection	64	-0.3003 ± 0.0767	-0.2313 ± 0.0798	-0.5728 ± 0.0566	-0.5285 ± 0.0608
All men of three series	136	-0.3062 ± 0.0524	-0.3003 ± 0.0526	-0.5147 ± 0.0425	-0.4995 ± 0.0434
Women.					
Original series	68	-0.2322 ± 0.0774	-0.2556 ± 0.0764	-0.3499 ± 0.0718	-0.3556 ± 0.0714
Supplementary series	35	-0.1796 ± 0.1103	-0.2764 ± 0.1053	-0.4755 ± 0.0882	-0.4778 ± 0.0880
Both series	103	-0.2034 ± 0.0637	-0.2465 ± 0.0624	-0.4976 ± 0.0500	-0.5016 ± 0.0497

Having considered the intensity of the interrelationship of age and total heat-production as measured on a universal standard scale, we may now consider the actual amount of change in metabolism which takes place with increase in age. This can best be done by expressing the relationship in the form of regression equations. In these prediction equations a = age in years, h = total heat per 24 hours, h_k = heat-production per 24 hours in calories per kilogram, and h_D = heat-production per 24 hours in calories per square meter of body-surface by the Du Bois height-weight chart. Inserting the proper values in the linear equations given on page 14 of Chapter II, we have the following values:

Men, original series, athletes, $N = 16$

$h = 2825.88 - 43.03\,a$ $\quad h_k = 25.071 + 0.025\,a$ $\quad h_D = 1119.61 - 6.17\,a$

Men, original series, others, $N = 62$

$h = 1671.89 - 2.45\,a$ $\quad h_k = 30.219 - 0.169\,a$ $\quad h_D = 1019.08 - 3.63\,a$

Men, original series, whole series, $N = 89$

$h = 1878.72 - 9.19\,a$ $\quad h_k = 29.241 - 0.134\,a$ $\quad h_D = 1045.07 - 4.38\,a$

Men, original series, Gephart and Du Bois selection, $N = 72$

$h = 1928.41 - 11.85\,a$ $\quad h_k = 28.322 - 0.098\,a$ $\quad h_D = 1061.81 - 5.25\,a$

Men, first supplementary series, $N = 28$

$h = 1698.79 - 3.65\,a$ $\quad h_k = 30.111 - 0.167\,a$ $\quad h_D = 1013.81 - 4.04\,a$

Men, original and first supplementary series, $N = 117$

$h = 1848.47 - 8.38\,a$ $\quad h_k = 29.366 - 0.139\,a$ $\quad h_D = 1037.51 - 4.29\,a$

Men, second supplementary series, $N = 19$

$h = 1845.34 - 6.40\,a$ $\quad h_k = 27.588 - 0.070\,a$ $\quad h_D = 1016.38 - 2.89\,a$

Men, other than Gephart and Du Bois selection, $N = 64$

$h = 1815.48 - 6.20\,a$ $\quad h_k = 28.862 - 0.116\,a$ $\quad h_D = 1014.29 - 3.20\,a$

Men, of three series, $N = 136$

$h = 1823.80 - 7.15\,a$ $\quad h^k = 28.703 - 0.112\,a$ $\quad h_D = 1022.17 - 3.60\,a$

Women, original series, $N = 68$

$h = 1448.54 - 3.52\,a$ $\quad h_k = 26.580 - 0.046\,a$ $\quad h_D = 927.58 - 2.33\,a$

Women, supplementary series, $N = 35$

$h = 1412.33 - 1.85\,a$ $\quad h_k = 28.590 - 0.147\,a$ $\quad h_D = 948.70 - 3.22\,a$

Women, both series, $N = 103$

$h = 1420.47 - 2.29\,a$ $\quad h_k = 28.308 - 0.124\,a$ $\quad h_D = 942.25 - 2.96\,a$

These equations fail to give the comparative view of the relationship between age and total heat and age and heat per unit of body-size that is afforded by the correlation coefficients. They give information of a very different and very essential sort concerning the relationship between age and heat-production.

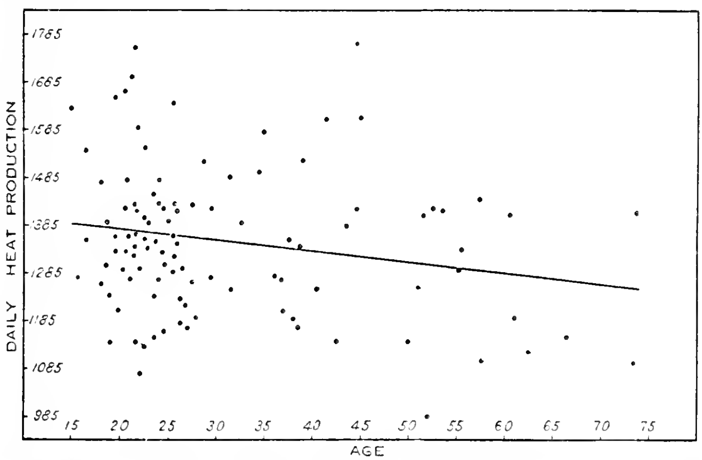

DIAGRAM 18.—Daily heat-production of women classified according to age.

The variable term of the equations for the regression of total heat on age shows that in the larger series of men the daily heat-production of an individual decreases by an average amount of 2.45 to 11.85 calories per 24 hours for each year of life. Naturally 7.15 calories, based on the whole series, must be taken as the most probable value. With the women the decrease in heat-production per 24 hours is 1.85 calories in the 35 supplementary women, 3.52 calories in the 68 women in the original series, and 2.29 calories in the whole (103) series. Naturally the latter value must be taken as the standard until further data are available.

Diagrams 18 and 19 show the distribution of the individual measurements with reference to the straight-line equations.

The regressions of heat per kilogram on age show that there is an average yearly decrease of from 0.098 to 0.169 calorie per kilogram per 24 hours in heat-production in the larger series of men and from 0.046 to 0.124 calorie per 24 hours in the larger series of women.

Absolute values are of course much larger in the case of body-surface because the number of square meters of area is much smaller than the number of kilograms of weight. The constants show an

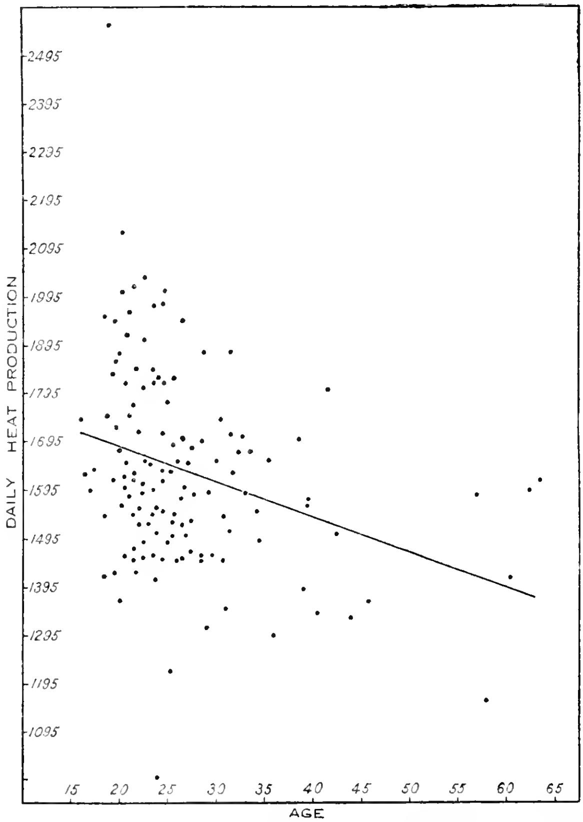

Diagram 19.—Daily heat-production of men classified according to age.

annual decrease of from 3.20 to 5.25 calories per square meter per 24 hours in the larger series of men and from 2.33 to 2.96 calories per square meter per 24 hours in the larger series of women.

In the foregoing discussion the influence of the factor of body-size has been to some extent minimized by expressing the decrease in heat-production in calories per kilogram of body-weight and in calories per square meter of body-surface as estimated by the Du Bois height-weight chart.

It is quite possible to correct for the influence of both stature and weight in a different way. We have already used the partial correla-

tion coefficients between age and heat-production for constant stature, ${}_{s}r_{ah}$, and between age and heat-production for constant body-weight, ${}_{w}r_{ah}$, and finally the partial correlation between age and heat-production for both stature and weight constant, *i.e.*, ${}_{sw}r_{ah}$.

These express the interrelationships between age and heat production, correction being made for stature, for weight, and for stature and weight, on a relative scale. To obtain the actual smoothed change in metabolism per year with correction for the influence of stature and weight we have merely to determine the partial regressions, ρ, *i.e.*,

$${}_{s}\rho_{ah},\ {}_{w}\rho_{ah},\ {}_{sw}\rho_{ah},$$

The needful regression slopes in calories per 24 hours are given by:

$${}_{w}\rho_{ah} = {}_{w}r_{ah}\frac{{}_{aw}\sigma_h}{{}_{wh}\sigma_a} \qquad {}_{s}\rho_{ah} = {}_{s}r_{ah}\frac{{}_{as}\sigma_h}{{}_{sh}\sigma_a}$$

where the partial correlations are already known (table 40) and the partial standard deviations are given by:

$${}_{as}\sigma_h = \sigma_h\sqrt{1-r_{ah}{}^2}\sqrt{1-{}_{a}r_{sh}{}^2} = \sigma_h\sqrt{1-r_{sh}{}^2}\sqrt{1-{}_{s}r_{ah}{}^2}$$

$${}_{sh}\sigma_a = \sigma_a\sqrt{1-r_{as}{}^2}\sqrt{1-{}_{s}r_{ah}{}^2} = \sigma_a\sqrt{1-r_{ah}{}^2}\sqrt{1-{}_{h}r_{as}{}^2}$$

$${}_{aw}\sigma_h = \sigma_h\sqrt{1-r_{ah}{}^2}\sqrt{1-{}_{a}r_{wh}{}^2} = \sigma_h\sqrt{1-r_{wh}{}^2}\sqrt{1-{}_{w}r_{ah}{}^2}$$

$${}_{wh}\sigma_a = \sigma_a\sqrt{1-r_{aw}{}^2}\sqrt{1-{}_{w}r_{ah}{}^2} = \sigma_a\sqrt{1-r_{ah}{}^2}\sqrt{1-{}_{h}r_{aw}{}^2}$$

The results for the larger series are set forth in table 41. Here the second column gives the decrease in heat-production per year in the

TABLE 41.—*Regression and partial regression of heat-production on age.*

Series.	N	ρ_{ah}	${}_{s}\rho_{ah}$	${}_{w}\rho_{ah}$	${}_{ws}\rho_{ah}$
Men.					
Gephart and Du Bois selection	72	−11.85	−12.40	−8.32	−9.13
Other than Gephart and Du Bois selection	64	− 6.20	− 3.78	−7.07	−6.12
Grand total	136	− 7.15	− 5.57	−7.27	−6.75
Women.					
Original series	68	− 3.52	− 3.82	−3.46	−3.53
Supplementary series	35	− 1.85	− 2.79	−4.87	−4.87
Grand total	103	− 2.29	− 2.73	−4.64	−4.68

several series. These are merely repeated from the list of equations on page 114. The three following columns give the smoothed annual decrements in heat-production corrected for the influence of stature, of weight, and of stature and weight. The entries in the two final columns are certainly much more uniform than those in the first two. Correction for body-weight and for stature and weight have greatly reduced the irregularities which are evident in the gross regressions or in the regressions corrected for stature only.

The reader personally unacquainted with the difficulties in the measurement of human metabolism may consider these results numerically very discordant. We have purposely set down the full series of equations to bring out this range of differences. To us—considering the great difficulties of measurement, the wide individuality of the subjects in physique, diet, and life-history, and the (statistically) small number of individuals considered—the results seem remarkably consistent. There are differences, to be sure, but so there are in the *first determination* of any chemical, physical, or astronomical constants. As the number of determinations increases it will be possible to give the statistical constants measuring the influence of age upon metabolism in men and women as a class with ever increasing precision.

TABLE 42.—*Alteration of metabolism with age.*

Age.	Men.				Women.			
	N	Mean total heat-production.	Mean heat per kilogram.	Mean heat per square meter.	N	Mean total heat-production.	Mean heat per kilogram.	Mean heat per square meter.
15−19 =17	11	1753	26.95	968.4	12	1371	26.51	894.8
20−24 =22	59	1676	26.10	946.2	35	1371	25.16	870.6
25−29 =27	33	1590	25.90	919.6	20	1335	25.83	868.5
30−34 =32	15	1624	25.59	913.1	4	1404	24.25	881.3
35−39 =37	7	1520	23.00	857.0	9	1322	24.32	828.3
40−44 =42	5	1511	24.58	867.8	6	1427	21.35	809.7
45−49 =47	1	1365	22.20	771.0	1	1608	26.80	975.0
50−54 =52	..	....	....	....	6	1269	21.12	772.2
55−59 =57	2	1373	24.70	864.0	4	1290	19.20	741.3
60−64 =62	3	1541	21.47	836.0	3	1238	22.20	768.3
65−69 =67	..	....	....	....	1	1150	20.60	723.0
70−74 =72	..	....	....	....	2	1253	21.10	768.0

The theoretical significance of these results will be discussed in the final section of this chapter. From the standpoint of practical application it is important to determine whether or not in the age range of adult life covered by our data, changes in metabolism with age can be sufficiently well represented by the slope of a straight line. If so, correction for age in clinical calorimetry will be a relatively simple problem.

Straight-line equations for a number of the series have been given on pages 114–115. These are based on observations ungrouped with respect to age. For purposes of graphical representation it has seemed desirable to class the individuals in quinquennial groups. Table 42 shows the method of grouping, the number of individuals, and the average heat-production in total calories, in calories per kilogram of body-weight, and in calories per square meter of body-surface by the Du Bois height-weight chart for 24-hour periods.

A comparison of the empirical means and the straight-line equations is made in diagrams 20 to 22. The empirical means are very irregular because of the small number of individuals in the higher age groups, resulting not merely from the fact that a division of 103 and 136 individuals into several groups must give small subclasses, but from the fact that the great majority of metabolism observations have been made on individuals between 20 and 35 years of age.

Notwithstanding this irregularity of the means, these diagrams seem to justify the following generalizations.

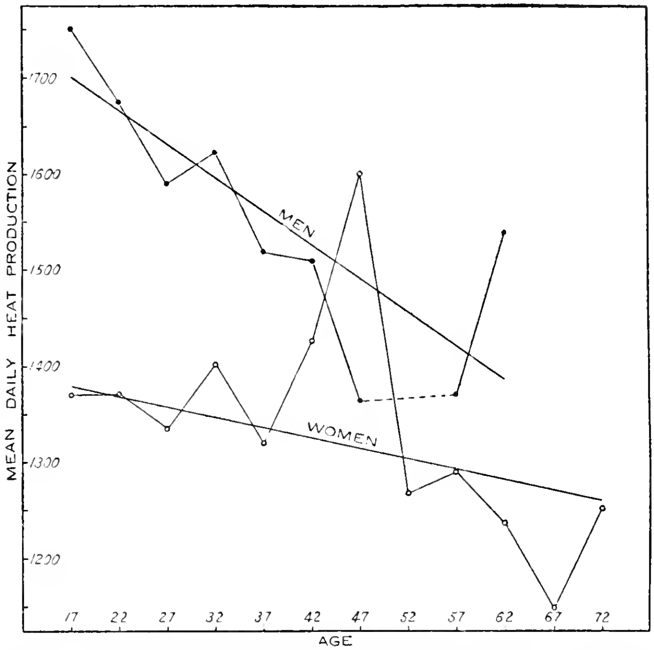

DIAGRAM 20.—Mean total daily heat-production of men and women classified according to age.

(1) There is far better agreement between the empirical and the theoretical means when heat-production is expressed in calories per square meter of body-surface than when given in terms of gross heat-production.

(2) From the graphs alone it is impossible to decide whether the expression of metabolism in calories per kilogram of body-weight has resulted in an improvement in the agreement of the empirical and smoothed means over that which is found when heat-production is recorded in total calories per 24-hour periods.

(3) The regression lines for men and women lie much closer together and are more nearly parallel when heat-production is expressed in relative terms, *i.e.*, in calories per kilogram or calories per square meter, than when given in terms of gross heat-production.

(4) Considering both sexes and the three lines for each, it is impossible to assert, on the grounds of inspection merely, that a curve of a higher order would be more suitable than a straight line for smoothing the means.

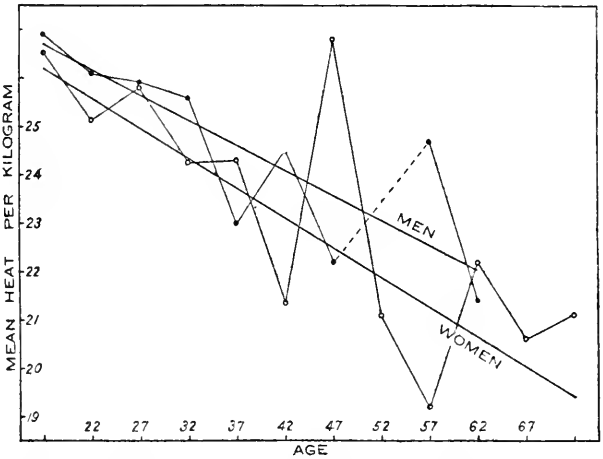

DIAGRAM 21.—Mean daily heat-production per kilogram of body-weight of men and women classified according to age.

(5) In all three relationships the line graduating the means for the men lies above that for the women. In general this is also true of the empirical means.

We note that (1) is merely another expression for results already demonstrated by the correlation coefficients, namely that the relation-

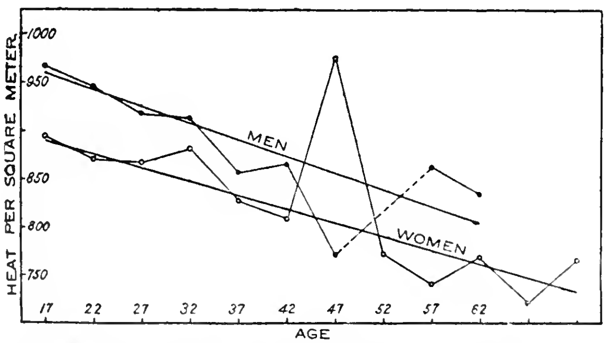

DIAGRAM 22.—Mean daily heat-production per square meter of body-surface of men and women classified according to age.

ship between age and heat-production is more intimate if correction be made for the irregularities of body-size.

Result (2) will be tested by statistical methods below. Results (3) and (5) are expressions of the sexual differentiation in adults which will be reserved for treatment in detail in Chapter VII.

We shall now turn to a more detailed consideration of (4). To test more critically the linearity of the regression of total heat-production on age we may have recourse to the calculation of the correlation ratio[9] and the application of Blakeman's test for linearity of regression.

To secure correlation ratios which shall be of value we must group with regard to age. Table 42 shows the age grouping adopted, the number of individuals, and the mean heat-productions in the total men and women.

For age and total heat-production as deduced from this table the correlation coefficient, r_{ah}, and correlation ratio, η_{ah}, are:

	Correlation coefficient, r.	*Correlation ratio, η.*
Men	-0.3017 ± 0.0526	0.3575 ± 0.0504
Women	-0.1946 ± 0.0639	0.3458 ± 0.0585

The correlation coefficients for the two sexes differ so greatly that one would be inclined at first to suspect arithmetical error, but the value for the women ungrouped with respect to age as recorded on page 111 is essentially identical with this constant, *i.e.*, -0.2034 ± 0.0637 as compared with -0.1946 ± 0.0639.

The correlation ratios are in much closer agreement than the correlation coefficients. With regard to their probable errors the correlation ratios do not differ. The difference between the correlations for men and women is 0.1071 ± 0.0827, a value which, while large in comparison with the constants upon which it is based, by no means represents a certainly trustworthy difference.

Applying Blakeman's criterion

$$\zeta/E_\zeta = \frac{1}{\chi_1} \cdot \frac{1}{2} \sqrt{\eta^2 - r^2} \frac{1}{1 + (1-\eta^2)^2 - (1-r^2)^2}$$

where χ_1 is the value of $0.6744898/\sqrt{N}$ from Miss Gibson's tables,[10] we find:

For men	$\zeta/E_\zeta = 1.72$
For women	$\zeta/E_\zeta = 2.33$

Applying the same methods to the problem of the interrelationship between age and total heat-production per kilogram of body weight we have for r_{ah_k} and η_{ah_k}:

	Correlation coefficient, r.	*Correlation ratio, η.*
For men	-0.3840 ± 0.0493	0.4414 ± 0.0466
For women	-0.4962 ± 0.0501	0.5695 ± 0.0449

The correlation coefficients and the correlation ratios are numerically higher in both sexes. The correlations are but slightly more

[9] Blakeman, Biometrika, 1906, 4, p. 332.

[10] Gibson, Biometrika, 1906, 4, p. 385. Also in Pearson's Tables for Statisticians and biometricians, Cambridge, 1914.

consistent than those for age and gross heat-production. The difference between the two sexes is only 0.1122 ± 0.0703, and is therefore insignificant in comparison with its probable error. The difference between the two correlation ratios is 0.1281 ± 0.0647, or approximately twice its probable error and of questionable biological significance.

Applying Blakeman's criterion we find:

For men.................. $\zeta/E_\zeta = 1.96$
For women............... $\zeta/E_\zeta = 2.23$

On the basis of the usual criterion, regression can not be asserted to be non-linear in either sex.

Turning now to the measures of heat-production corrected for body-size by reduction to calories per square meter of body-surface by the Du Bois height-weight chart, we have for r_{ah_D} and η_{ah_D}:

	Correlation coefficient, r.	*Correlation ratio, η.*
For men	−0.4584 ± 0.0457	0.5008 ± 0.0433
For women	−0.5149 ± 0.0489	0.5824 ± 0.0439
Difference	0.0565 ± 0.0669	0.0816 ± 0.0617

Again the differences between the constants for men and women can not be considered to differ significantly. Blakeman's criterion gives

For men................ $\zeta/E_\zeta = 1.80$ For women........... $\zeta/E_\zeta = 2.16$

The results can not be considered to show that regression is non-linear. The calculation of the correlation ratios and the interpretation of the results of Blakeman's test on a series of only 136 and 103 individuals presents some difficulties. We have not applied the corrections to the correlation ratio suggested by Pearson and "Student," nevertheless we feel justified in concluding from the results of Blakeman's test and from the graphical test of the linearity of regression that throughout the age range involved the change in metabolism with age can be satisfactorily represented by a straight line. When larger series of data are available the use of regression coefficients of a higher order may be justified.

A discussion of the practical application of correction for age is reserved for Chapters VII and VIII. Before leaving the subject of the change of metabolism with age, it seems desirable to compare the heat-production per square meter of body surface by the Du Bois height-weight chart given by our equations for total men (N = 136) and for total women (N = 103) with the "normal standards" for various ages calculated by Aub and Du Bois[11] from their age curve and that given by Lusk.[12]

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[11] Aub and Du Bois, Arch Intern. Med., 1917, **19**, p. 831. Also Cornell, Univ. Med. Bull., 1918, **7**, No. 3, 19th paper, p. 9.

[12] Lusk, Science of Nutrition, Philadelphia, 3 ed., 1917, p. 129.

The results in terms of calories per square meter per 24 hours appear in table 43.

Without exception the values of daily heat-production as given by Aub and Du Bois are higher, and sometimes very materially higher, than those indicated by our equations showing the regression of heat-production per square meter of body-surface by the height-weight chart on age.

3. COMPARISON OF CHANGES IN PULSE-RATE IN RELATION TO AGE.

We now turn to a comparison of the changes in another physiological character. It seems desirable in this connection to consider the possible relationship between age and pulse-rate.

TABLE 43.—*Comparison of Aub and Du Bois standard normal with daily metabolism given by regression equation.*

Age in years.	Men.			Women.		
	Aub and Du Bois normal standard.	Metabolism as given by equation.	Difference.	Aub and Du Bois normal standard.	Metabolism as given by equation.	Difference.
14–16 (15)	1104	968	+136	1032	898	+134
16–18 (17)	1032	961	+ 71	960	892	+ 68
18–20 (19)	984	954	+ 30	912	886	+ 26
21–30 (25.5)	948	930	+ 18	888	867	+ 21
31–40 (35.5)	948	894	+ 54	876	837	+ 39
41–50 (45.5)	924	858	+ 66	864	808	+ 56
51–60 (55.5)	900	822	+ 78	840	778	+ 62
61–70 (65.5)	876	786	+ 90	816	748	+ 68
71–80 (75.5)	852	750	+102	792	719	+ 73

Our data for adults give the correlations between age and pulse-rate shown in table 44. The partial correlations, given by

$$ {}_sr_{ap} = \frac{r_{ap} - r_{as} r_{sp}}{\sqrt{1-r_{as}^2}\,\sqrt{1-r_{sp}^2}} \qquad {}_wr_{ap} = \frac{r_{ap} - r_{aw} r_{wp}}{\sqrt{1-r_{aw}^2}\,\sqrt{1-r_{wp}^2}} $$

are laid beside the gross values.

All the correlations are numerically low. Taken individually no one of the series would be regarded as certainly significant in comparison with its probable error by any careful statistician. Considering the series as a whole and noting that 9 out of the 11 constants are negative in sign, we consider that there is a reasonable probability that pulse-rate decreases with age. This probability is increased when correction is made for the possible influence of weight and height. The partial correlations, ${}_wr_{ap}$, ${}_sr_{ap}$, are the same in sign as the original correlations.

Since correction for the two most conspicuous physical characters of the individual have left the relationship between age and pulse-rate

practically unchanged, there can be little doubt that there is a slight but definite relationship between these two variables in the range of age covered by our data for adults. Pulse-rate decreases slightly with advancing years. This decrease is not directly due to any change in stature or weight.

As far as we are aware the only correlations available from the literature are those provided by Whiting.[13]

TABLE 44.—*Correlation between age and pulse-rate and partial correlation between age and pulse-rate for constant stature and constant body-weight.*

Series.	N	Correlation between age and pulse-rate r_{ap}	$\frac{r_{ap}}{E_{r_a}}$	Partial correlation between age and pulse-rate $_wr_{ap}$	$\frac{_wr_{ap}}{E_{_wr_{ap}}}$	Partial correlation between age and pulse-rate $_sr_{ap}$	$\frac{_sr_{ap}}{E_{_sr_{ap}}}$
Men.							
Original series:							
Athletes	16	-0.2597 ± 0.1573	1.65	-0.2189 ± 0.1605	1.36	-0.0343 ± 0.1684	0.20
Others	62	$+0.0581 \pm 0.0583$	0.68	$+0.1146 \pm 0.0845$	1.36	$+0.0744 \pm 0.0852$	0.87
Whole series	88	-0.1405 ± 0.0705	1.99	-0.1405 ± 0.0705	1.99	-0.1297 ± 0.0707	1.83
Gephart and Du Bois selection	71	-0.0963 ± 0.0793	1.21	-0.1180 ± 0.0789	1.50	-0.0969 ± 0.0793	1.22
First supplementary series	28	-0.0609 ± 0.1270	0.48	-0.0743 ± 0.1268	0.59	-0.0623 ± 0.1270	0.49
Original and first supplementary series	116	-0.1252 ± 0.0616	2.03	-0.1257 ± 0.0616	2.04	-0.1170 ± 0.0618	1.89
Other than Gephart and Du Bois selection	50	-0.1947 ± 0.0918	2.12	-0.2177 ± 0.0909	2.39	-0.1461 ± 0.0934	1.56
All men of three series	121	-0.1483 ± 0.0600	2.47	-0.1500 ± 0.0599	2.50	-0.1400 ± 0.0601	2.33
Women.							
Original series	68	-0.1250 ± 0.0805	1.55	-0.1323 ± 0.0804	1.65	-0.1338 ± 0.0803	1.67
Supplementary series	22	$+0.1084 \pm 0.1421$	0.76	$+0.1566 \pm 0.1403$	1.12	$+0.1177 \pm 0.1418$	0.83
Both series	90	-0.0855 ± 0.0706	1.21	-0.0313 ± 0.0710	0.44	-0.0760 ± 0.0707	1.07

For age and pulse-rate in 500 criminals examined by Goring the correlations deduced by Whiting are:

For age and pulse	$r_{ap} = +0.121 \pm 0.022$
For age and pulse with temperature constant	$_tr_{ap} = +0.174 \pm 0.022$
For age and pulse with respiration constant	$_rr_{ap} = +0.117 \pm 0.022$
For age and pulse with stature constant	$_sr_{ap} = +0.124 \pm 0.022$
For age and pulse with weight constant	$_wr_{ap} = +0.107 \pm 0.022$
For age and pulse with both weight and stature constant	$_{ws}r_{ap} = +0.097 \pm 0.022$

These values, both the gross correlation between age and pulse-rate and the correlation corrected for various other physical and physiological characters, are low but consistently positive throughout. Thus they indicate that pulse-rate increases with age instead of decreasing as in our series. This contradictory result may possibly be due to the essentially different conditions under which the rates were measured. Our determinations were made with the subject lying down and at complete muscular repose in the post-absorptive state; they, therefore, probably represent the minimum or basal pulse-rate for individuals in their state of nutrition. Goring's countings were made with the patient sitting in his cell after early dinner, either idle, reading, or writing. The

[13] Whiting, Biometrika, 1915, **11**, pp. 8–19.

average pulse-rate found by Whiting for these data was 74.22, which is 12.96 beats or 21.2 per cent higher than our average for men. Possibly pulse-rate in older individuals is more susceptible to increase due to physiological or physical activity than it is in younger. If so, this difference in the conditions under which the rates were measured, may be sufficient to account for the differences in the correlations.

4. RECAPITULATION AND GENERAL CONSIDERATIONS.

In this chapter we have considered the relationship between age and basal metabolism in adult men and women. The significance of such an investigation is twofold. From the theoretical side the morphological and physiological changes which accompany the aging of the individual constitutes one of those groups of fundamental problems which has always attracted the interest of biologists and of the medical profession. Any contribution of actual fact is a valuable addition to the vast literature. From the practical standpoint, a knowledge of the quantitative relations between age and basal metabolism is essential for the establishment of standard controls to be used in applied calorimetry.

The results of the present study show that throughout the whole range of what we commonly designate as adult life the heat-production of the individual decreases. The correlation between age and heat-production is therefore negative in sign, lower daily heat-production being associated with greater age. The gross correlations are of the order −0.31 for men and −0.20 for women.

Daily heat-production has been shown in the foregoing chapter to be correlated with both stature and body-weight. Since in adult life these vary for the most part independently of age, it is evident that if the correlation between age and metabolism be due to definite and progressive physiological changes in the tissues of the organism with increasing age, the measure of the correlation between age and metabolism will be lowered by the disturbing influence of these factors.

Correcting for the influence of stature makes relatively little difference in the intensity of the correlation between age and metabolism. Correction for the influence of body-size by expressing heat-production in calories per kilogram of body-weight raises the numerical value of the correlation coefficient for age and heat-production from −0.31 to −0.41 in the total series of men and from −0.20 to −0.49 in the total series of women. If correction be made for body-size by expressing heat-production in calories per square meter of body-surface as estimated by the Du Bois height-weight chart, the correlation is increased (in the negative direction) from −0.31 to −0.47 for the men and from −0.20 to −0.52 for the women.

Comparable results are obtained by correcting the correlations between age and heat-production for the influence of physical dimen-

sions by the use of partial correlation formulas. If the partial correlation between age and metabolism for constant stature and body-weight be compared with the gross or uncorrected correlations, it will be found that the numerical values of the interdependence of the two variables has been raised from −0.31 to −0.50 for the men and from −0.20 to −0.50 for the women.

These statistical results indicate in the clearest way the existence of fundamental changes in the tissues and their physiological activities with age. This evidence inheres not merely in the fact that the intensity of the interrelationship is increased when correction is made for the disturbing influence of body mass in both of the sexes, but that when these corrections are made the results for the two sexes are rendered very nearly identical.

Expressing the relationships between age and metabolism in terms of the actual decrease in daily heat-production per year, we note that this amounts to about 7.15 calories in men and 2.29 calories in women. Of course men and women differ greatly both in stature and weight and in daily heat-production. The decrease in heat-production per kilogram of body-weight is more nearly identical in the two sexes, *i.e.*, 0.112 calorie in men and 0.124 calorie in women. The decrease in calories per square meter of body-surface area, as estimated by the Du Bois height-weight chart, is 3.60 calories per 24 hours per year in men and 2.96 calories per 24 hours per year in women.

The problem of the regression of heat-production (either gross heat-production or heat per kilogram of body-weight or per square meter of body-surface) on age is one of both great theoretical interest and practical importance. It is of great physiological interest to determine the rate at which metabolism decreases with advancing years, to ascertain whether this changes at some period of life, and (if so) how these rates of change or periods of change correspond with other physiological periods. Certainly this phase of the problem of growth, age, and death should take rank with the others which have been investigated. The quantitative statement of the laws governing the change in metabolism with age is the first logical step in the analysis of this problem.

From the practical standpoint, determination of these laws is essential for the calculation of standard control values to be used as a basis of comparison in physiological and pathological research.

Tests of the rate of change throughout the age-range of adult life indicate that it is essentially uniform, so that, as far as the data at present are adequate to show, it can be expressed as well by the slope of a straight line as by a curve of a higher order.

The data for the lower and higher age-groups are still inadequate, and the exact limits of applicability of a straight line for the expression of changes in metabolism with age must remain a problem for future consideration.

Practically the linear nature of the change of metabolism with age is of great importance in connection with the establishment of standard control series to be used in applied calorimetry—a subject to be fully discussed in Chapter VIII.

For the purposes of throwing some light on the general problem of senescence, we have brought together for comparison such quantitative data as are available on the changes of another physiological character with age.

Pulse-rate in our own data shows a slight decrease with increasing age. The amount of change is so small that its nature has not been investigated.

Referring to the problem of senescence, rejuvenescence, and death in man and other higher animals, Child[14] says:

> "As regards the relation between senescence, death, and rejuvenescence, the higher animals and man differ from the lower organisms in the limitation of the capacity for regression and rejuvenescence under the usual conditions. *Senescence is therefore more continuous than in the lower forms*[15] and results in death, which is the final stage of progressive development. These characteristics of man and the higher animals are connected with the evolutionary increase in the physiological stability of the protoplasmic substratum and the higher degree of individuation which results from it."

Now, without passing any judgment on the validity of Child's extension to the higher vertebrates of his remarkable experimental results with planarians and other lower forms, we may point out that our own quantitative results fully substantiate his conclusion concerning the greater continuity of senescence in the higher forms. In man, changes in metabolism after physical maturity are not merely *continuous*, they are *uniform* in amount, so that they can be reasonably well represented by the slope of a straight line.

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[14] Child, Senescence and Rejuvenescence, Chicago, 1915, p. 399.
[15] Italics ours.

CHAPTER VI.

A CRITIQUE OF THE BODY-SURFACE LAW.

The simple relation between the volume and the surface-area of comparable solids has always appealed to biologists. Absorption, secretion, or excretion, whether of water, of aqueous solutions, or of gases, are *surface* phenomena. Gills, lungs, glands, or other organs which are highly specialized for these functions in the higher organisms are primarily characterized by great surface exposure. Thus the well-being of the organism as a whole in many ways depends upon the ratio of the surface-area to the mass of many of its tissues.

Again, except when great changes in the proportion of parts are concomitant with increase in size, it is evident that growth must decrease the ratio of external surface-area to body-mass. In phylogeny the same relationship obtains as in ontogeny. In organisms of generally similar physical conformity, the larger species must expose a relatively smaller surface. It is therefore natural that one should find the two-thirds power relationship considered in various general writings on body-size. A whale in the Arctic exposes relatively far less surface to the surrounding water than a flying-fish in the tropics. An auk in the Arctic exposes relatively far less surface for the loss of heat than a humming-bird in the tropics. Biologists have not failed to grasp the possible significance of such facts for geographical distribution.

Turning to an entirely different phase of the general discussion, we may refer to the investigations of Dreyer, Ray, and Walker,[1] in which they considered blood-volume, area of the cross-section of the trachea, and area of the cross-section of the aorta in various animals and birds in relation to this principle.

Surface rather than volume has been suggested as an important factor in muscular work. In the problem of the physiology of excretion it has been stated that the volume of urine is not proportional to the weight of the kidney but to the internal surface. Snell and Warnecke have attempted to arrange vertebrates in series according to relative brain-weight, brain-surface, and intelligence. Perhaps the most extreme application of the principle in biological theory is that in Mühlmann's theory of old age, which depends upon the change in the relation of surface and volume with increasing size.[2]

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[1] Dreyer and Ray, Phil. Trans., 1909–1910, **201**, ser. B, p. 133. Dreyer, Ray, and Walker, Proc. Roy. Soc., 1912–1913, **86**, ser. B, pp. 39 and 56.

[2] See bibliography and extensive discussions of Mühlmann's writings by Minot, The Problem of Age, Growth, and Death, 1908, and by Child, Senescence and Rejuvenescence, 1916.

Given an inert body at a temperature higher than its medium, the rate of loss of heat will be determined to a large degree by the nature and extent of its surface-area and the difference in temperature of the body and its medium. For three-quarters of a century, or more, various physiologists have urged that the heat-production in different individuals and species of animals is proportional to their surface-area.

Our purpose in this chapter is threefold: (*a*) To outline briefly the history of the so-called body-surface law. (*b*) To discuss certain physiological evidences bearing upon the question of its validity. (*c*) Finally, to test it by the application of biometric formulas to the series of data available for this investigation.

1. HISTORICAL.

While discussions of the so-called "body-surface law" generally begin with the work of Rubner,[3] and while it is frequently referred to as "Rubner's Law" the conception of surface and volume relationships in the balance between thermolysis and thermogenesis seems to have been quite prevalent at least among French writers, at a much earlier date. Thus Robiquet and Thillaye, in reporting on a memoir submitted to the Academy of Medicine of Paris [4] by Sarrus and Rameaux, refer to the arguments of the authors as based upon "une proposition de géométrie incontestable, une loi physique généralement admise et quelques faits physiologiques plus ou moins bien constatés." These they state as follows:

"Voici donc les bases sur lesquelles s'appuie le travail dont il s'agit.

"1° Entre deux polyèdres semblables, les volumes sont comme les cubes, et les surfaces comme les carrés des côtés homologues.

"2° Toute chose étant égale d'ailleurs, des corps de même nature perdent à chaque instant des quantités de chaleur qui sont proportionnelles à l'étendue de leur surface libre.

"3° Dans les animaux de même espèce, considérés à l'état normal et placés dans des conditions identiques, les quantités de chaleur développée dans un temps donné sont proportionnelles aux quantités d'oxygène absorbé par l'acte de la respiration, ou bien encore sont proportionnelles au volume d'air inspiré pendant la même durée; en admettant toutefois que l'air introduit dans les poumons à chaque inspiration abandonne toujours la même proportion de son oxygène.

"Si actuellement nous admettons que la température des animaux est constante, c'est reconnaître que chez eux il y a une parfaite égalité entre la chaleur qu'ils produisent et celle qu'ils émettent. Or, comme la déperdition est proportionnelle à l'étendue des surfaces libres et que celles-ci sont comme le carré des côtés homologues, il faut nécessairement que les quantités d'oxygène absorbé, ou, ce qui est l'équivalent, que la chaleur produite d'une part et perdue de l'autre soit comme le carré des dimensions correspondantes des animaux que l'on compare, condition indispensable et qui peut être remplie de plusieurs manières."

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[3] Rubner, Zeitschr. f. Biol., 1883, **19**, p. 535.

[4] Robiquet and Thillaye, Bull. Acad. roy. de méd., Paris, 1839, **3**, p. 1094.

The memoir by Rameaux and Sarrus was never published in full by the *Académie de Médecine*, but abstracts had appeared earlier in *Comptes Rendus* [5] and through a letter to Quetelet in the *Bulletins de l'Académie Royale de Bruxelles*,[6] and the final memoir was read by Rameaux before the Belgian Academy in 1857 and published in 1858.[7]

In none of these publications is the proposition that heat-production is proportional to body-surface emphasized as a new conception. In his volume of 1889 Richet,[8] in referring to one of his tables, calls attention to "la démonstration physiologique de ce fait bien connu que la production de calorique est fonction de la surface et non du poids."

Ten years after the appearance of Rameaux's preliminary papers Bergmann [9] attempted to explain the relatively higher food demands of small as compared with those of larger animals of the same species by the generalization that the heat-production of a body is proportional to its surface. Bergmann's work was entirely comparative and theoretical. While Rameaux in his final memoir brought together and analyzed considerable series of data for pulse-rate, respiration-rate, and lung-capacity, the first experimental evidence seems to have been that presented by Müntz [10] who in discussing the maintenance food requirement for horses as investigated in a series of experiments made in 1879 gives a clear statement of the conception of the relationship between body-surface and metabolism. Although his experiments contribute nothing of importance to the general problem, his conception is of sufficient importance, historically at least, to be quoted in full:

"Il nous semble, dès à présent, que la quantité d'aliments nècessaire à l'animal pour s'entretenir sans travailler doit se trouver plutôt en rapport avec la surface qu'avec le poids de son corps. Toutes choses égales d'ailleurs, on peut admettre que la quantité de chaleur enlevée au corps est proportionnelle à sa surface. Une notable partie de l'aliment est certainement consommée pour l'entretien de la chaleur vitale qui tend constamment à se perdre, par rayonnement ou par conductibilité, dans le milieu ambiant. Une autre cause de refroidissement est l'évaporation cutanée qui est fonction de la surface du corps, si elle ne lui est pas proportionnelle. L'évaporation produite par les organes respiratoires peut également être regardée comme ayant un rapport avec la surface bien plus qu'avec le poids. Nous sommes donc, par ces considérations, autorisés à admettre l'influence prépondérante de la surface du corps sur la quotité de la ration d'entretien.

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[5] Sarrus and Rameaux, Compt. rend. Acad. sci., Paris, 1838, **6**, p. 338; loc. cit., 1839, **9**, p. 275.

[6] Rameaux, Bull. Acad. roy. d. sci. de Bruxelles, 1839, **6**, (2), p. 121.

[7] Rameaux, Mém. couron. Acad. roy. d. sci. (etc.) de Belg., Brux., 1858, **39**, 64 pp.

[8] Richet, La chaleur animale, Paris, 1889, p. 222.

[9] Bergmann and Leuckart, Anatomisch-physiologische Übersicht des Thierreichs, Stuttgart, 1852, see especially p. 272. Also Bergmann, Ueber die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse, Göttingen, 1848. An earlier paper in Müllers' Archiv, 1845, p. 300 is also cited.

[10] Müntz, in an article entitled "Recherches sur l'alimentation et sur la production du travail," in Annales de l'Institut National Agronomique, Paris, 1880, **3**, pp. 23–61. This quotation is from p. 59. According to a statement on p. 25. "Les expériences de la 3[me] série ont duré du 12 Septembre 1879 au 7 Fevrier 1880, c'est-à-dire pendant 148 jours."

"Plus tard nous apporterons à l'appui les expériences que nous faisons dans cette direction et qui sont rendues possibles grâce au concours de M. Lavalard et de M. Poret, grâce aussi a l'obligeant empressement avec lequel MM. Geoffroy Saint-Hilaire et Ménard ont mis à notre disposition les précieuses ressources du Jardin d'acclimatation."

The first experimental data which requires consideration in relation to modern work was published almost simultaneously by Rubner [11] and Richet [12] both of whom maintained that the heat lost from living organisms is essentially constant per unit of body-surface. Because of his unusual technique the work of Rubner has rightfully been accorded the greater weight by physiologists, and the "body-surface law" is generally referred to as "Rubner's law." It has unquestionably been one of the most stimulating ideas in nutritional physiology.

While this constancy of heat-production per unit of body-surface area is the dominant note in Rubner's papers, in several instances he writes as if a causal relationship between body-surface and heat-production was by no means thoroughly established. Richet, too, lays stress upon many factors, such as nature of integument and external temperature.

After the appearance of Rubner's paper the hypothesis of a simple mathematical relationship between body-surface and total metabolism became naturally the subject of much discussion. Magnus-Levy and Falk [13] referred to Rubner's dictum as the most important recent contribution in the study of the gaseous metabolism. The range in the animal kingdom over which this supposed law has been assumed to extend is astonishing. It has been extensively applied to variations in the heat-productions of the same species. The computations of E. Voit [14] attempt to show that animals ranging in size from a 2-kilogram fowl to a 441-kilogram horse have essentially the same heat-production per square meter of body-surface, namely, 970 calories per 24 hours. Armsby and his collaborators,[15] referring to a series of constants for man, cattle, horses and swine say:

"They show a rather striking degree of uniformity and tend to confirm the conclusions of E. Voit that the basal katabolism of different species of animals is substantially proportional to their body-surface."

An illustration of the extremes to which strict adherence to the body-surface law may lead is afforded by Pütter's contention [16] that the "active" surface, *i.e.*, the cell surfaces of the various organs of the body, should be taken into account, Pütter maintaining that the energy

[11] Rubner, Zeitschr. f. Biol., 1883, **19**, p. 535.
[12] Richet, La chaleur animale, Paris, 1889. His earlier writings, some of which appeared at about the same time as Rubner's paper, are here summarized.
[13] Magnus-Levy and Falk, Arch. f. Anat. u. Physiol., Physiol. Abt., Supp., 1899, p. 314.
[14] Voit, Zeitschr. f. Biol., 1901, **41**, p. 120.
[15] Armsby, Fries, and Braman, Proc. Nat. Acad. Sci., 1918, **4**, pp. 3–4. See also Journ. Agric. Research, 1918, **13**, pp. 49–55.
[16] Pütter, Zeitschr. f. allg. Phys., 1911, **12**, p. 125.

consumption is proportional not to the body-surface but to the area of the lung-surface.

A careful study of the large mass of literature on metabolism subsequent to 1883 will show that there has been at no time a fixed interpretation of the relationship between body-surface and heat-production. Even the most ardent advocates of the body-surface law have at times called attention to noticeable abnormalities. But attempts were made to explain these discrepancies by the nature of the integument, the density of the fur and hair coverings, and variations in the amount of body-surface exposed.[17]

To attempt to review in any detail the extensive discussions of the earlier writers would be a useless task.

Unfortunately many modern authors are not so conservative in their expressions as to the cause of this relationship between body-surface and heat-production as were earlier students. The attitude maintained in more recent times may be illustrated by the following quotations. In his deservedly oft-cited contribution on respiration in Schaefer's Physiology, Pembrey says:[18]

"Now, small mammals and birds have a temperature equal to or even higher than that of large animals of the same classes; and, on account of the relatively greater surface which they expose for the loss of heat, they must have a relatively far greater production of heat than the large animals, for there is generally no marked difference in the protective coat of fur or feathers."

While Minot[19] does not explicitly state that heat-loss and heat-generation are determined by body-surface, his comparison and discussions would seem to have this implication.

The range of applicability over which Rubner himself would consider the surface law valid is perhaps indicated by a quotation from a paper of 1908,[20] in which he discusses the metabolism of various mammals after birth. Referring to the values used, he says:

"Wenn es auch nicht immer Neugeborene waren, die der Stoffwechseluntersuchung unterzogen sind, so wissen wir auf Grund des von mir erwiesenen Oberflächengesetzes, dass bei den Säugern ihr Stoffwechsel nicht des Masse, aber genau der Oberfläche proportional verläuft. Man kann daher die gewünschten Grössen des Energieverbrauchs für jede beliebige Kleinheit der Thiere, also auch für die Neugeborenen, durch Rechnung finden."

Lefèvre specifically states that the application of the law of Newton to living animals is illusory,[21] but in his discussion of the production of heat per unit of surface the following statement appears:[22]

[17] For example, we frequently find in the text of the earlier writers such statements as the following: "Wärmeabgebende Fläche und Hautfläche sind zwei sehr verschiedene Dinge." Rubner, Beiträge zur Ernährung im Knabenalter mit besonderer Berücksichtigung der Fettsucht, Berlin, 1902, p. 40.

[18] Pembrey, Schaefer's Text-Book of Physiology, London, 1898, 1, p. 720.

[19] Minot, The Problem of Age, Growth, and Death, New York, 1908, pp. 18–20.

[20] Rubner, Sitzungsb. d. Kgl. Preuss. Akad. d. Wissensch., phys.-math. Kl., 1908, p. 36.

[21] Lefèvre, Chaleur Animale et Bioénergétique, Paris, 1911, p. 379.

[22] Lefèvre, *loc. cit.*, p. 500.

"La production chez l'homéotherme est *en équation* avec la perte calorique. Or, à pouvoir émissif égal, la déperdition est évidemment proportionnelle à la surface rayonnante. La production calorique (c'est-à-dire, chez l'organisme en équilibre et au repos, le besoin d'énergie) est donc proportionnelle à l'étendue de la surface totale du corps."

Furthermore, Professor H. P. Armsby, whose more recent conclusions have been noted above, states: [23]

"The results which we have been considering show that in general the emission constant, *i.e.*, the rate of heat emission per unit of surface, is substantially the same in small and large animals and that the greater loss of heat in the former case is met by an increased production. In this aspect the effect is simply an extension of the influence of falling temperature, the increased demand for heat being met by an increased supply, so that the extent of surface appears as the determining factor of the amount of metabolism."

Moulton, who (on the basis of a series of graphs) has given a detailed discussion of the interrelationship between body-surface, body-weight, blood-volume, nitrogen-content of body, etc., in cattle in various conditions, says: [24]

"A better conception of the basal needs of animals for food can be obtained from a comparison of the relative surface areas of the animals. Since Rubner and Richet presented evidence to show that the heat production of living animals was proportional to the body surface, this has been a much used unit of reference."

In other current (1915) literature we find such statements as the following: [25]

" 'Rubner's law,' to quote from Lusk, is that 'the metabolism is proportional to the superficial area of an animal. In other words, the metabolism varies as the amount of heat loss at the surface, and its variance in accordance with this law is necessary for the maintenance of a constant temperature.' "

In a popular text-book on nutrition [26] we also find:

"Since the body loses heat in proportion to the extension of its surface it is not strange that this is the determining factor for the metabolism."

Du Bois, in his Harvey lecture [27] of November 27, 1915, said:

"Rubner demonstrated many years ago that the metabolism is proportional to the surface-area of the body and that for each square meter of skin large men, small men, dogs, horses, and mice have about the same heat pro-

[23] Armsby, The Principles of Animal Nutrition, New York, 1906, 2d ed., p. 365. Professor Armsby, in a recent personal communication states that this phraseology does not exactly express his belief: "The true state of the case is, as I conceive it, that the body does not produce heat to any considerable extent to keep itself warm but is kept warm because it produces heat. In other words, heat production is substantially not an end but an incident of metabolism."

[24] Moulton, Journ. Biol. Chem., 1916, **24**, p. 303.

[25] Means, Journ. Med. Research, 1915, **32**, p. 139.

[26] Stiles, Nutritional Physiology, Philadelphia, 1915, 2d ed., p. 200.

[27] Du Bois, Am. Journ. Med. Sci., 1916, **151**, p. 781. Also Studies Dept. Physiol., Cornell Univ. Med. Bull., 1917, 6, No. 3, Part II. Also The Harvey Lectures, 1915–1916, p. 106.

duction. Just why this should be we do not know. It reminds us at once of Newton's law that the cooling of bodies is proportional to their surface-area, but the metabolism does not follow this law when the external temperature is raised or lowered."

The foregoing review, while fragmentary, may give a general idea of the attitude of physiologists toward the problem of body-surface area in relation to metabolism. One essential distinction has not always been clearly drawn by those who have written on the so-called body-surface law. One may inquire whether the law holds for the different species of animals which vary greatly in size, or he may inquire whether it is valid when applied to individuals differing in size within the same species. In brief the *inter-specific* and the *intra-specific* applicability of the so-called law present two different problems. It is quite conceivable that it might be very applicable *intra-specifically* but not inter-specifically or *vice versa*.

In this volume we shall limit ourselves chiefly to the question of *intra-specific* applicability.

2. PHYSIOLOGICAL EVIDENCE ON THE BODY-SURFACE LAW.

Direct physiological evidence of an experimental nature of two sorts are available. The first is that afforded by determinations of metabolism in similar organisms subjected to different external temperature. The second is that afforded by measures of metabolism secured on individuals of like body-surface but in different physiological state.

The physical basis of the body-surface law has often been stated to be Newton's "law of cooling." Some of the earlier physiological writers seem to have fully understood the nature of Newton's law, but in recent years a confused and inadequate conception of this law has established itself in physiological literature. Physiologists have stated the physical law as they would like it to be rather than as it really is.

For example the immediately foregoing quotation from one of the Harvey lectures [28] is quite typical of the conception of Newton's law which has been held by physiologists, including the workers at the Nutrition Laboratory.

But Newton's law is not primarily a surface law at all, but a law of the rate of cooling, now known to have only a limited applicability even in the simpler cases of controlled physical experimentation. Heat is lost by cooling bodies by convection, conduction, and radiation. The relative importance of these three methods depends upon the nature of the surface and the nature of the surrounding medium. In the majority of cases of transference of heat all these modes are simultaneously operative in a greater or less degree, and the combined effect is generally of great complexity. The different modes of transference

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[2] The Harvey Lectures, 1915–1916, p. 106.

are subject to widely different laws, and the difficulty of disentangling their effects and subjecting them to calculation is often one of the most serious obstacles in the experimental investigation of heat under the controlled conditions of the physical laboratory.

If one assumes the applicability of Newton's law to living organisms it is evident that it might under special conditions reduce to a surface law. Thus in 1898 Richet [29] wrote:

"Supposons, en effet, qu'il s'agisse d'un corps inerte; sa radiation sera, conformément à la loi de Newton, égale à la différence des deux températures, multipliée par sa surface S $(t—t')$. En supposant $t—t'$ constant, ou peu variable, il s'ensuit que la radiation calorique est proportionnelle à la surface. Or j'ai pu prouver que les chiffres calorimétriques expérimentalement obtenus sont tels que l'unité de surface dégage toujours à peu près la même quantité de calories."

In modern discussions of the body-surface law the question of the nature of the integument is generally ignored. Yet in the earlier writings the nature of the surface received detailed consideration.

This subject is discussed in detail by Richet,[30] who not merely treats it from the comparative side but records experiments with animals in normal condition, with shaved animals, and with those whose fur had been smoothed down by a coating of oil or varnish. He even gives the results of experiments with animals having white, gray, and black coats, and claims differences in their heat loss.[31]

Since Newton's law is really a law of the rate of cooling *due to differences in temperature*, it should be evident that its validity when applied to organisms could be tested only by having all basal-metabolism determinations made under comparable conditions of internal and external temperature. Certainly this can not be assumed of the series of determinations on diverse organisms which are brought together for comparison in substantiation of the body-surface law.

Among the earlier physiologists who had not yet lost sight of the true significance of Newton's law, studies of metabolism at varying temperatures were seriously considered. When the influence of environmental temperature was studied, difficulties were immediately encountered. In discussing the fact that certain animals show abnormal relationships between the environmental temperature and their body temperature, d'Arsonval[32] introduces the following significant sentence:

Cela tient évidemment à ce que la surface rayonnante *physiologique* de l'animal n'est pas constante comme sa surface physique. Aux basses températures, le phénomène se complique d'une constriction vasculaire périphérique, qui restreint considérablement le pouvoir rayonnant de l'animal à égalité de

[29] Richet, Dictionnaire de Physiologie, Paris, 1898, 3, p. 130.
[30] Richet, La Chaleur Animale, Paris, 1889; see especially Chapter XI.
[31] Richet, *loc. cit.*, p. 237.
[32] d'Arsonval, Mem. Soc. de Biol., 1884, 8 ser., 1, p. 723.

surface *physique.* Cela montre que la connaissance de la surface géométrique d'un animal est insuffisante pour qu'on en puisse déduire la perte par rayonnement: il faut encore tenir compte de l'état de la circulation périphérique.

In 1888 v. Hoesslin [33] pointed out that while in warm-blooded animals variations in the external temperature are followed by variations in metabolism, the change in heat-production is not proportional to the change in external temperature. Thus heat-loss is not determined solely by difference in body-temperature and air-temperature, *i.e.*, by differences in potential. v. Hoesslin considers this a valid refutation of Rubner's theory.

Richet, in his volume of 1889,[34] treated the problem of metabolism under varying external temperature. The reader interested in details may refer to this work or to a more recent discussion of the problem.[35]

We now turn to the question of the influence of internal condition on metabolism in its relation to the problem of the validity of the body-surface law. We shall here consider the problem as to whether, when body-surface remains practically constant but other conditions vary, the heat-production per square meter of body-surface area is a constant.[36]

Against this line of argument is to be urged the fact that in an early consideration of the body-surface law Rubner insisted upon uniformity of physiological state.[37] While in more recent writings the constancy or equality in the nutritional level has from time to time been emphasized as a prerequisite for the applicability of the law of surface-area, this has by no means been generally considered, and current practice has tended to accept the universality of this law irrespective of whether the individual is poorly or well nourished.

As early as 1888 v. Hoesslin [38] pointed out that a dog (studied in the respiration chamber by Pettenkofer and Voit) required 1600 calories per day for maintenance of body-weight. On the sixth day of inanition it used only 1190 and on the tenth day only 940 calories. Body-weight decreased from 33 to 30 kg. If the body-surface law holds, the heat-production of the two periods should stand in the ratio $\sqrt[3]{33^2} : \sqrt[3]{30^2}$ or 10.288 : 9.655, or there should be a decrease in heat-production of

$$\frac{100\left(\sqrt[3]{33^2}-\sqrt[3]{30^2}\right)}{\sqrt[3]{33^2}}=6.15 \text{ per cent.}$$

As a matter of fact there is a decrease of 41.25 per cent.

[33] v. Hoesslin, Arch. f. Anat. u. Phys., Phys. Abt., 1888, pp. 327–328.

[34] Richet, La Chaleur Animale, Paris, 1889; especially Chapter XI.

[35] Richet, Chaleur, in Dictionnaire de Physiologie, 1898, **3**, p. 138.

[36] Here only published materials are taken into account. An extensive series of under-nutrition experiments made on a group of 25 men was carried out through the winter of 1917–1918 by the Nutrition Laboratory. The problem of the relation of nutritional state to metabolism is considered in detail in the report of these experiments. See Benedict, Miles, Roth, and Smith, Human vitality and efficiency under prolonged restricted diet, Carnegie Inst. Wash. Pub. No. 280. (In press.)

[37] Rubner, Archiv. f. Hyg., 1908, **66**, p. 89.

[38] v. Hoesslin, Arch. f. Anat. u. Phys., Phys. Abt., 1888, p. 331.

A discrepancy in Von Hoesslin's reasoning should be pointed out here, in that the value of 1600 calories was that found during feeding and thereby unquestionably included the stimulating effect of the meat. Consequently the true basal value would be somewhat lower and the decrease on the tenth day is undoubtedly somewhat less than 41.5 per cent, but in any event probably of much greater magnitude than the 6.15 per cent computed on the ratio of the body surfaces.

Again, v. Hoesslin points out that Rubner's own dogs show the same decrease in metabolism with inanition. Rubner introduced a table to show "dass sich der Stoffwechsel bei Hunger fast gar nicht ändert." Yet this table shows a decrease in the metabolism in absolute terms of 33 per cent, in relation to body-weight of 20 per cent, and in relation to body-surface of 25 per cent.

In an experiment upon a dog which was confined to the laboratory for several months and which did not lose weight,[39] the metabolism decreased very considerably (19 per cent). When the dog was again allowed country life, her metabolism returned to essentially its original value, but the body-weight was unchanged. Here evidently is constancy in body-surface area, but variation in heat-production per square meter.

Information with regard to the metabolism of human individuals who are well or poorly nourished is, for the most part, obtained by observations on different subjects. But during prolonged fasting we may observe in the same person changes in the plane of nutrition fully comparable to those roughly characterized as poorly or well nourished. It is thus seen that during prolonged fasting simultaneous measurements of the body-surface and the basal metabolism of the subject have an unusual value. A 31-day fasting experiment made in the Nutrition Laboratory has a particular interest in this connection.[40]

A study of the relationships of body-weight, body-surface, and basal metabolism during fasting is all the more important when it is remembered that it is commonly believed that the fasting animal rapidly adjusts itself to the minimum metabolism. The results of earlier experiments on the dog, the cock, and the guinea pig [41] indicate that per kilogram of body-weight the fasting metabolism is constant. With the fasting man the metabolism per kilogram of body-weight was not constant. Furthermore, calculation of the metabolism per square meter of body-surface on the basis of the Meeh formula—the only one available at the time of the experiment—indicated a large loss in heat-production during the progress of the fast. Realizing the desirability

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[39] Lusk, Journ. Biol. Chem., 1915. 20, p. 565,

[40] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915.

[41] Armsby, The Principles of Animal Nutrition, New York, 1906, 2d ed., p. 346.

of checking the results, a photographic method [42] of measuring surface-area was developed and the values of heat-production per square meter of body-surface [43] were recomputed.

The subject took no food and only about 900 c.c. of distilled water per day for 31 days.[44] The heat-production during the night was measured directly with the bed-calorimeter for each of the 31 nights.[45] As the fast progressed there was a very noticeable decrease in heat-production from night to night. This would naturally be expected since weight decreased from about 60 kg. to about 47.5 kg. But the metabolism when computed on the basis of body-weight showed a decided loss as the fast progressed. There was also a loss in metabolism per square meter of body-surface. This is shown by the data in table 45, which gives the body-weight, the body-surface as computed by the Meeh formula [46] and from the measurements of the anatomical photographs, and the heat-production per square meter of body-surface per 24 hours as based upon the observations with the bed-calorimeter during the night.

Disregarding the last food day prior to the fast, the heat-production per square meter per 24 hours as given in the last column of the table ranges from 927 calories on the third day to 664 calories on the twenty-first day of the fast, representing a decrease of 28 per cent in the heat-production per square meter of body-surface. Thereafter a distinct tendency for the heat-production to increase was apparent.

In the absence of any marked change in body-temperature the difficulty of considering the loss of heat from the surface of the body as the determining factor in the metabolism of this fasting man is very

[42] Benedict, Am. Journ. Physiol., 1916, **41**, p. 275.

[43] Benedict, *loc. cit.*, p. 292.

[44] The fasting man remained (so far as ocular evidence is concerned) for the most part physiologically normal during the progress of the fast. Strength tests made with the hand dynamometer showed practically no change with the right hand and but a slight decrease with the left hand, although there was an almost immediate evidence of fatigue in the first two or three days of the fast. While there was naturally a certain amount of weakness observable in the last few days, the subject, after having been without food for 31 days, spoke extemporaneously before a body of physicians for approximately three-quarters of an hour, standing during the whole period and vigorously gesticulating. Later in the day he sang and danced. It is thus clear that we have here to do not with a fasting man who is in the last stage of emaciation and in a moribund condition but with an individual who, judged from ocular evidence, would appear not at all unlike the normally emaciated type of individual. Furthermore, the body-temperature did not materially alter. His average body-temperature in the bed-calorimeter experiment on the night of the last day of the fast was but 0.3° C. below that of the night of the second day, a difference which indicates no marked disturbance of the body-temperature. While the pulse-rate was distinctly lower at the end of the period than at the beginning, it will be seen that the subject underwent the 31-day fast without great loss of muscular strength or material alteration of body-temperature.

[45] It was likewise computed indirectly from the carbon-dioxide excretion and oxygen consumption during the same period. Reference must be made to the original publication for the methods of calculation and for a discussion of the heat-production per kilogram of body-weight, in which an attempt was made to reduce the observation of each night to a common standard.

[46] It will be seen from the figures that, using as a standard the body-surface values obtained with the photographic method, the body-surface as computed from the Meeh formula is invariably too large and consequently the heat-production per square meter computed from this measure of the body-surface is too small.

great. Had the body-temperature fallen materially the explanation of the decrease in heat-production could easily be made on the basis of difference in temperature potential. No such explanation is, however, at hand. Fully confirmatory results in experiments on a squad of 12 men, maintained for a long period on a much reduced diet have been briefly stated in Chapter IV, p. 103.

TABLE 45.—*Heat produced by fasting subject during experiments in bed calorimeter at night.*

Date.	Day of fast.	Body-weight without clothing	Body-surface.		Heat produced per square meter per 24 hours.	
			By Meeh formula.	Computed from photographic measurements.	Meeh formula.	Photographic method.
1912		*kilos.*	*sq. meters*	*sq. meters*	*cals.*	*cals.*
Apr. 13–14		60.87	1.91	*1.71	858	958
14–15	1st	59.86	1.88	1.70	817	904
15–16	2d	58.91	1.86	1.68	830	918
16–17	3d	58.01	1.84	*1.66	836	927
17–18	4th	57.22	1.83	1.66	827	912
18–19	5th	56.53	1.81	1.66	764	833
19–20	6th	56.01	1.80	1.65	774	845
20–21	7th	55.60	1.79	1.65	760	825
21–22	8th	55.18	1.78	1.65	790	852
22–23	9th	54.74	1.77	1.65	720	772
23–24	10th	54.25	1.77	*1.65	725	778
24–25	11th	53.94	1.76	1.64	715	767
25–26	12th	53.64	1.75	1.64	712	760
26–27	13th	53.48	1.75	1.63	709	761
27–28	14th	53.22	1.74	1.62	698	749
28–29	15th	52.92	1.74	1.62	649	698
29–30	16th	52.40	1.73	1.61	639	687
Apr. 30–May 1	17th	51.91	1.71	*1.60	642	686
May 1– 2	18th	51.57	1.71	1.60	653	698
2– 3	19th	51.21	1.70	1.60	676	719
3– 4	20th	50.97	1.69	1.60	666	704
4– 5	21st	50.60	1.69	1.59	625	664
5– 6	22d	50.22	1.68	1.59	653	690
6– 7	23d	50.00	1.67	1.59	655	688
7– 8	24th	49.70	1.67	*1.59	651	684
8– 9	25th	49.40	1.66	1.58	637	670
9–10	26th	49.10	1.65	1.57	695	731
10–11	27th	48.78	1.64	1.57	673	703
11–12	28th	48.52	1.64	1.56	676	711
12–13	29th	48.19	1.63	1.55	691	726
13–14	30th	47.79	1.62	1.54	698	734
14–15	31st	47.47	1.61	*1.53	701	737

* Body surface for days on which photographs were obtained, *i.e.*, April 13, 16, 23, 30, and May 7 and 14. Other values obtained by interpolation.

Turning from the results of prolonged starvation experiments on man to those obtained by Armsby and Fries [47] for a fattening experiment on a steer, we note that they observed an increase of 36 per cent

[47] Armsby and Fries, Journ. Agric. Research, 1918, 11, p. 461.

in the basal katabolism [48] in the fattened state. This they attribute in part to the greater body-weight to be supported in standing, but they point out that the increase in heat-production with fattening is more rapid than the increase in body-weight or in body-surface as estimated by the Meeh formula. "Apparently the accumulation of fat tended in some way to stimulate the general metabolism."

3. MEASUREMENT OF BODY-SURFACE AREA.

When one thinks of a physical or biological "law" he naturally assumes that the measurements upon which it is grounded are adequate in number and reliability to justify fully the formulation of the generalization under consideration.

Du Bois and Du Bois [49] freely admit that the whole question of the validity of Rubner's Law "rests on the accuracy of the determinations of the basal metabolism and of the surface-area." They also point out that "The methods of determining the metabolism have been greatly improved, leaving the surface-area the doubtful factor." It seems worth while, therefore, to summarize briefly the actual measurements of body-surface area upon which the comparisons underlying the body-surface law rest.

In much of the work which has been done on the inter-specific applicability of the "law" the measures of body-surface can hardly be dignified as approximations. Richet [50] compared the surfaces of his rabbits on the assumption that they were spheres. Certain investigators have used the constant term for the *horse* in estimating the body-surface of *swine* by the Meeh formula. Finally Pütter [51] has apparently used the same formula for mammals ranging in form from the camel to the walrus!

Even when we turn to so intensively studied an organism as man, we find that, to quote the Du Boises again, "the number of formulæ for surface-area determination is large, the number of individuals whose area has been measured is small."

Du Bois and Du Bois give a list and brief discussion of at least the chief of the various formulas which have been proposed. In view of the fact that most of these have received practically no attention from physiologists, it seems unnecessary to discuss them here where we are concerned primarily with the question of the adequacy of the actual measurements upon which formulas have been based.

Meeh [52] in 1879 published the results of his painstaking measurements of 6 adults and 10 children, using a variety of methods.

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[48] Basal katabolism in ruminants must be determined under conditions in some regards essentially different from those obtaining in investigations on man and the carnivora. For the details the special literature of animal metabolism must be considered.

[49] Du Bois and Du Bois, Arch. Intern. Med., 1915, **15**, p. 868.

[50] Richet, La chaleur animale, Paris, 1889, p. 222.

[51] Pütter, Zeitschr. f. Allg. Biol., 1911, **12**, p. 201.

[52] Meeh, Zeitschr. f. Biol., 1879, **15**, pp. 425–458.

Fubini and Ronchi [53] measured one man, marking out the anatomical regions of the body and determining the areas geometrically.

Bouchard [54] measured five adults.

Lissauer [55] measured 12 dead babies, only one of which he considered a normal child, by covering the body with silk paper and then measuring the area of the paper geometrically or with a planimeter.

Sytscheff [56] measured 10 infants under one year of age but computed no constants.

Du Bois and Du Bois [57] measured the surface-area of 5 individuals with great care.

TABLE 46.—"*Constant" term of Meeh formula as determined by direct measurement.*

Subject.	Observer.	Age in years.	Height in centimeters.	Weight, in kilos.	Measured body-surface, sq. cm.	Constant for Meeh formula.
Benny L.	D. B. and D. B.	36.	110.3	24.20	8473	10.13
Hagenlocher	Meeh	13.1	137.5	28.30	11883	12.80
Very thin woman.	Bouchard	....	....	31.80	12737	12.69
Korner	Meeh	15.7	152.	35.38	14988	13.17
Schneck	Meeh	36.	158.	50.00	17415	12.96
Adult man	Fobini and Ronchi	....	....	50.00	16067	11.84
Nagel	Meeh	45.	160.	51.75	18158	12.96
Fr. Brotheck	Meeh	17.7	169.	55.75	19206	13.16
Naser	Meeh	....	170.	59.50	18695	12.27
Normal man	Bouchard	....	....	61.60	18930	12.13
Fr. Haug	Meeh	26.2	162.	62.25	19204	12.01
Morris S.	D. B. and D. B.	21.	164.3	64.00	16720	10.45
R. H. H.	D. B. and D. B.	22.	178.	64.08	18375	11.49
Forstbauer	Meeh	66.	172.	65.50	20172	12.48
E. F. D. B.	D. B. and D. B.	32.	179.2	74.05	19000	10.55
Normal woman	Bouchard	....	....	76.50	19484	10.81
Kehrer	Meeh	36.	171.	78.25	22435	12.26
Large man	Bouchard	....	....	88.60	21925	11.03
Mrs. Mc. K.	D. B. and D. B.	....	149.7	93.00	18592	9.06
Very fat man	Bouchard	....	....	140.00	24966	9.26

In the development of a graphic method of determining body-surface area,[58] 20 individuals were photographed in different selected positions and the areas of the prints were determined by means of the planimeter.

Du Bois and Du Bois [59] give a table which we reproduce in a somewhat modified form herewith, table 46, showing that actual surface-area measurements have been made on a total of 20 adult individuals.

[53] Fubini and Ronchi, Moleschott's Untersuchungen z. Naturlehre, 1881, **12**.

[54] Bouchard, Traité de pathologie générale, Paris, 1900, **3**, p. 200, 384.

[55] Lissauer, Jahrb. f. Kinderheilk, N.F., 1903, **58**, p. 392.

[56] Sytscheff, Measurement of volume and surface of children of varying ages, Diss., St. Petersburg, 1902. (From the Clinic of Children's Diseases of Professor Gundobin). See also Gundobin, Die Besonderheiten des Kindesalters, Berlin, 1912, pp. 53–54 (section on body surface of children; quotes Sytscheff and gives table of Sytscheff's measurements on p. 54

[57] Du Bois and Du Bois, *op. cit.*

[58] Benedict, Am. Journ. Physiol., 1916, **41**, p. 275.

[59] Du Bois and Du Bois, *loc. cit.*, p. 871.

To what extent do these measurements justify the formulas which have been based upon them?

The constant term of both the Meeh and the Lissauer formula is given by

$$k = a' / \sqrt[3]{w^2}$$

where a' is the directly measured body-surface area.

Meeh's observations gave constants entered in the final column of table 46.[60] Those for Lissauer's group of 12 babies [61] are given in table 47.

Now the "constants," both those for adults whose surface-area was measured by Meeh, Fubini and Ronchi, Bouchard, and Du Bois and Du Bois, and those for infants whose surface-area was measured by Lissauer, show great differences among themselves. Thus in the adult series we find the actually determined "constant" terms ranging from 9.06 to 13.17. Yet Meeh in his original publication *retained six or seven significant figures* in recording his constants, notwithstanding the fact that constants obtained when both sides of the body were actually measured differed from those in which one side only was measured in the *third or fourth significant figure* in every case. In Lissauer's infants the "constants" range from 8.92 to 12.40. This great discrepancy was fully recognized by Lissauer who, emphasizing the great variation in the individual determinations, chose 10.3 as that most free from criticism.

TABLE 47.—*Constants of Lissauer's babies.*

Child.	K *	K
No. 1	10.985	......
2	10.278	9.881
3	9.921	......
4	10.387	......
5	8.922	......
6	10.926	10.245
7	10.284	9.245
8	12.402	10.732
9	10.130	9.530
10	9.953	9.377
11	(10.287)	(8.472)
12	10.30	......

If we determine the standard deviation and the coefficients of variation of these "constant" terms we have the following results:

For 20 adults, measured by Meeh and others:

$\bar{k} = 11.676 \qquad \sigma_k = 1.2400 \qquad V_k = 10.62$

For 12 infants measured by Lissauer:

$\bar{k} = 10.398 \qquad \sigma_k = 0.7834 \qquad V_k = 7.53$

The coefficients of variation express the results in the most easily comprehensible form. We see that there is a variation of 10.6 per cent in the adults and of 7.5 per cent in the infants. In other words

[60] In 5 cases the constants recomputed by ourselves do not agree exactly with those given by Meeh. We have, however, used the values given by him.

[61] These are the constants given by Lissauer. Their calculation has not been rechecked. The first column (K*) givest he constant determined from the weight just before or after death. The second (K) gives the constant calculated from the baby's maximum weight.

the variability about (that is above and below) the mean value is 10.6 and 7.5 per cent of this mean value in adults and infants respectively.

What is the real significance of this result? It shows that physiologists have been regarding as a *constant* a figure which when actually determined shows a variability about two or three times that of stature in man! Surely no careful observer would consider the statures of the men he passed on the street identical. Yet physiologists have been using a selected value from series two or three times as variable and dignifying it as a "*constant.*"

While the present discussion is limited to the problem of the validity of the surface law in man, it is not without interest to note that Moulton, in his investigation of the surface area of cattle,[62] has found a wide variation in the value of k. The formulas which he proposes to use differ according to the fatness of the animals.

Determining the statistical constants of the values of k entered in table 5 of Trowbridge, Moulton and Haigh, we have:

$$\bar{k} = 9.097 \qquad \sigma_k = 0.8915 \qquad V_k = 9.80$$

Again we find a variation in the values of the "constant" which is relatively large, that is about 10 per cent of the average value. The futility of using a "constant" which is so little constant as this k is fully admitted by Trowbridge, Moulton and Haigh when they use different values for animals in different conditions.

Thus the Meeh method is no more satisfactory in its application to animal than to human calorimetry.

Fortunately conditions in work on human metabolism have been much improved by the studies of Du Bois and Du Bois, resulting in the development of the linear formula and of the height-weight chart which has been used throughout this chapter and which is destined to replace entirely the Meeh formula. Computations based upon the latter have, however, been given along with those based on the height-weight chart in many of the tables of the following discussion, since historically the theories considered date from the time when the Meeh formula was the only one available.

4. INADEQUACY OF CRITERIA OF VALIDITY OF BODY-SURFACE LAW HITHERTO EMPLOYED.

There has been in the past and prevails at present great diversity of opinion concerning the validity and range of applicability of the surface law. These differences of opinion are founded in part on tradition. In so far as they rest upon study of the available facts concerning

[62] Trowbridge, Moulton, and Haigh, Univ. Mo. Agric. Expt. Sta., Research Bull. No. 18, 1915, p. 14. Moulton, Journ. Biol. Chem., 1916, 24, pp. 303–307.

the measured metabolism of individuals of known or estimated body-surface, the situation seems to be about the following.

Series of measurements of basal metabolism have been made and expressed in calories per individual, per kilogram of body-weight, and per square meter of body-surface for definite periods of time. The number of calories produced by individuals varies greatly. When reduced to a standard of calories per square meter of body surface, the heat-production varies much less widely than when the original measurements are left entirely uncorrected for the size of the individual experimented with.

Workers of one group look at such series of values and seeing the great increase in uniformity of results which has been secured by the correction for body-surface exclaim, "The heat production of an individual per unit of body-surface is a physiological constant." Workers of another group, however, see the differences which still obtain between the measurements based upon a number of individuals and reply, "Certainly, with differences of such magnitude, no one can speak of calories per square meter of body-surface as a physiological constant."

Thus the two groups are apparently in a state of controversial dead-lock which can not be broken by the willingness of one or the other, or of both, parties to look at the other side of the shield, for both groups are already examining the same surface. One group sees in it regularity, the other irregularity. What constitutes regularity as contrasted with irregularity is a matter of personal opinion and must always remain so until some quantitative criterion is adopted.

The expression of the amount of heat produced in terms of number of calories per square meter of body-surface is, in its final analysis, merely an attempt to correct for the most significant proximate factors in the determination of heat-production. Since body-surface has the weight of tradition in its favor, it is perhaps naturally assumed to be the most significant factor. But suppose that body-surface is *not* the most significant variable physiologically? Certainly, it should not then be used as the corrective term.

The first step in determining the most potent physiological factor underlying heat-production would seem to be the actual measurement of the intensity of relationship between the various body measurements that may reasonably be suggested as influencing metabolism and total heat-production. We shall then be in a position to consider what measurement of this kind, or what combination of measurements, is most suitable for use as a corrective term to be applied to gross values of basal metabolism obtained from series of human individuals.

As far as we are aware, the most quantitative test[63] which has ever

[63] After this manuscript was nearly completed a paper by Armsby and his associates, in which correlations for body-weight and heat-production and body-surface and heat-production were given for the original Nutrition Laboratory series, appeared. Armsby, Fries, and Braman, Proc. Nat. Acad. Sci., 1918, 4, pp. 3–4. See also Journ. Agr. Res., 1918, 13, pp. 49–55.

been applied toward the solution of the problem of the relative value of body-weight and of body-surface as a means of correcting for differences in the total metabolism due to differences in the size of the individual has been the simple determination of the average percentage deviation from the mean value for the whole series of individuals of the measures of heat-production per kilogram of body-weight and per square meter of body-surface.

Thus Gephart and Du Bois [64] give the values shown in table 48 for the percentage deviation of calories per kilogram per hour from the mean number of calories per kilogram per hour and of calories per square meter of body-surface per hour from the mean of calories per square meter of surface per hour.

TABLE 48.—*Comparison of percentage variation of heat-production per kilogram of body-weight and per square meter of body-surface.*

Subject.	Calories per kilogram per hour.	Calories per meter per hour.	Percentage variation from average.	
			Calories per kilogram.	Calories per sq. meter.
F. G. B.	1.01	35.8	− 4	+ 5
G. L.	1.00	34.8	− 5	+ 2
F. A. R.	0.95	32.4	− 9	− 5
E. F. D. B.	1.00	34.1	− 5	0
John L.	0.92	30.9	−12	−10
J. J. C.	0.96	31.7	− 8	− 7
J. R.	1.00	32.8	− 5	− 4
R. H. H.	1.18	37.9	+14	+11
L. C. M.	1.11	35.1	+ 6	+ 3
F. C. G.	1.10	34.2	+ 5	0
Louis M.	1.21	36.7	+16	+ 7
T. M. C.	1.13	33.8	+ 8	− 1
Average	1.05	34.2	±8.1	±4.6

The average of the percentage deviations of the individual measures of heat production in terms of calories per kilogram of body-weight from the general mean of this measure is clearly higher than the average of the percentage deviations of the measures in units of calories per square meter of body-surface from the mean of all of the measures by this method.

The means given by Gephart and Du Bois stand in the ratio of 8.1 to 4.6.

If instead of using average deviations without regard to sign, as Gephart and Du Bois have done, we compute the standard deviations and coefficients of variation of the number of calories per kilogram of body-weight and per square meter of body-surface, we find the following values.

[64] Gephart and Du Bois, Arch. Intern. Med., 1915, **15**, p. 852.

For calories per kilogram per hour: $\sigma = 0.0908$ $V = 8.67$
For calories per square meter per hour: $\sigma = 1.962$ $V = 5.74$

The results confirm those obtained by the average deviation in indicating greater variability in measures of heat-production per unit of weight.

The same point may be brought out in a somewhat different and not altogether satisfactory manner by comparing the coefficients of variation for number of calories per kilogram of body-weight with the coefficients of variation for calories per square meter of body-surface in our various adult series. This is done in table 49.[65]

TABLE 49.—*Comparison of coefficients of variation of heat-production expressed in various units.*

Series.	N	Coefficient of variation of heat per kilogram of body-weight.	Coefficient of variation of heat per square meter, Meeh formula.	Coefficient of variation of heat per square meter, height-weight chart.
Men.				
Original series:				
Athletes	16	5.99	3.92	3.97
Others	62	10.60	7.75	6.95
Whole series	89	9.73	7.48	8.25
Gephart and Du Bois selection	72	8.07	6.68	6.75
First supplementary series	28	7.79	6.40	7.04
Original and first supplementary series	117	9.30	7.25	7.10
Second supplementary series	19	9.64	8.53	8.13
All men of three series	136	9.36	7.44	8.05
Women.				
Original series	68	11.90	8.21	7.51
Supplementary series	35	15.84	12.27	11.13
Both series	103	14.14	10.29	9.17

On first consideration these results would seem to fully justify the assertion that among groups of men of varying weight metabolism is proportional to surface-area according to Rubner's law and is not proportional to body-weight. Extreme caution must, however, be exercised in the physiological interpretation of such a relationship. The fact that the measures in terms of calories per square meter of surface show a smaller percentage of variation from their average value than do measures in terms of calories per kilogram of body-weight does not necessarily have any relationship whatsoever to physiological constants or to causal physiological relationships.

Consider this question somewhat more minutely. A series of measurements of total heat-production, h, in n individuals are made. These are $h_1, h_2, h_3, \ldots h_n$. The body-surfaces $s_1, s_2, s_3, \ldots s_n$ and the

[65] This method of analysis has the disadvantage that coefficients of variation are calculated from ratios of heat-production to body-weight and to body-surface. Thus an index of an index is used.

body-weights w_1, w_2, w_3, ... w_n for each individual are available; the following ratios are determined:

$$\frac{h_1}{w_1}, \frac{h_2}{w_2}, \frac{h_3}{w_3}, \ldots \frac{h_n}{w_n} \qquad \frac{h_1}{s_1}, \frac{h_2}{s_2}, \frac{h_3}{s_3}, \ldots \frac{h_n}{s_n}$$

Clearly enough the variability of the ratios will be determined not merely by the variability of the values of h but by the variability of the values of w and s as well. If the relationship between w and s be such that one of them is necessarily more variable than the other, the ratio in which the more variable measure is employed must of necessity be more variable also.

Now this is precisely the condition which obtains in the relationship between body-weight and body-surface. In computing body-surface by the Meeh formula, the deviation of the surface-area of an individual from its mean bears only the ratio of $\sqrt[3]{w^2}$ to the deviation of the weight from the average weight of the series.

TABLE 50.—*Comparison of coefficients of variation for body-weight and two measures of body-surface.*

Series.	N	Coefficient of variation for body-weight.	Coefficient of variation for body-surface by Meeh formula.	Coefficient of variation for body-surface by height-weight chart.
Men.				
Original series:				
Athletes	16	17.43	11.44	10.15
Others	62	14.32	9.43	7.55
Whole series	89	16.68	10.92	9.05
Gephart and Du Bois selection	72	13.22	8.74	7.76
First supplementary series	28	16.72	11.40	10.15
Original and first supplementary series	117	16.73	11.03	9.26
Second supplementary series	19	11.22	7.43	6.14
All men of three series	136	16.06	10.60	8.89
Women.				
Original series	68	19.78	12.76	8.80
Supplementary series	35	19.61	12.97	9.63
Both series	103	20.35	13.24	9.34

Thus a lower variability of surface-area as compared with body-weight is an arithmetical necessity. Conversely, a higher variability of the ratio of total heat to body-weight (*i.e.*, of the measures of heat-production in terms of calories per kilogram) is a statistical consequence of the use of the Meeh formula or of direct measurement of body-surface in individuals reasonably similar in physical configuration. It is presumably a necessary consequence of the use of the body-surfaces given by the Du Bois height-weight chart also.

How great may be the differences in the variability of the physical measurements themselves is readily seen by expressing the variabilities of body-weght and surface-area in relative terms as in table 50.

Here comparison is made of the coefficients of variation,

$$V_w = \frac{100\sigma_w}{\bar{w}} \qquad V_s = \frac{100\sigma_s}{\bar{s}}$$

where σ denotes the standard deviations and the bars indicate the means, for body-weight and body-surface as measured by the two methods. Without exception the measures of body-surface show a lower percentage of variation than do the measures of body-weight.

It is inevitable that the greater variability of body-weight—a purely mathematical phenomenon, not physiological—should influence any ratios into which body-weight enters. It is quite possible that the difference in the variability of calories per kilogram and in calories per square meter of body-surface due to this factor may be so great as to invalidate any judgment concerning the physiological significance of ratios to body-weight or body-surface based on inspection and personal judgment merely.[66]

Objections essentially similar to the above may be raised against one of the earliest series of calorimetric experiments, those of Richet, [67] who, working with rabbits of weights ranging from about 200 to nearly 4,000 grams, concluded "La perte de chaleur est fonction de la surface." Richet arranged his animals according to weight and calculated the average heat-production per kilogram for the ascending weight classes. The constants in this table lead to the "Résultat des plus intéressants et des plus nets, puisqu'il nous montre combien, avec l'augmentation de volume, diminue la production de chaleur par kilogramme du poids de l'animal." He also arranges the same animals according to weight and determines the loss of heat per unit of surface on the assumption that the areas of the animals bore to each other the relationship of surfaces of spheres of comparable weights. From these figures he concludes "On voit quelle ressemblance il y a entre ces chiffres, très proches les uns des autres."

But close examination shows that the heat-production per unit of body-surface decreases with the increasing weight of the animals, though apparently at a far lower rate than in the case of that per kilogram of weight. Without more detailed information and closer analysis it is impossible to say to what extent the greater decrease (when heat-production is expressed in calories per kilogram) is due to the fact that the volume of a solid is necessarily more variable than its surface.

There is a statistical difficulty in classifying animals by weight and computing the average heat per unit of weight for each weight

[66] The logical fallacy of deciding between weight and surface as a basis of reference has apparently been overlooked by even so keen an analyst as Moulton (Journ. Biol. Chem., 1916, 24, p. 320), who says: "On this basis the smallest variations are shown in the heat-consumption per unit of body-surface and the greatest variations in the heat-consumption per unit of body-weight."

[67] Richet, La chaleur animale, Paris, 1889; see pp. 219–221.

group.[68] Suppose, for purposes of argument, that the Nutrition Laboratory tenet that metabolism is proportional to the active protoplasmic mass, stimulus being considered constant, is valid. Let m_1, m_2, m_3 . . . . m_n be the active protoplasmic masses of a series of individual animals of weights w_1, w_2, w_3, ... w_n and heat-productions in total calories per unit of time h_1, h_2, h_3, ... h_n respectively. Then

$$\frac{h_1}{m_1}=\frac{h_2}{m_2}=\frac{h_3}{m_3}= \quad . \quad . \quad . \quad . \quad =\frac{h_n}{m_n}=k,$$

or the ratio of the total heat-production to the active protoplasmic mass (the unknown and undoubtedly highly complex and variable stimuli being taken as the same in all cases) is a constant.

But practically m is never known, and the ratio which has been used is

$$\frac{h_1}{w_1}, \quad \frac{h_2}{w_2}, \quad \frac{h_3}{w_3}, \quad . \quad . \quad . \quad . \quad \frac{h_n}{w_n}$$

The observed fact that this ratio is not a constant has been the ground for the rejection of weight as a basis for expressing heat-production and in part the reason for the adoption of body-surface as a standard for this purpose.

TABLE 51.—*Correlation between body-weight and heat-production per kilogram of body-weight.*

Series.	N	r_{wh_k}	$\frac{r_{wh_k}}{E_{r_{wh_k}}}$
Men.			
Original series	89	-0.6284 ± 0.0433	14.51
Gephart and Du Bois selection	72	-0.5552 ± 0.0550	10.09
First supplementary series	28	-0.6143 ± 0.0794	7.74
Second supplementary series	19	-0.4977 ± 0.1164	4.28
All men of three series	136	-0.6076 ± 0.0365	16.65
Women.			
Original series	68	-0.7742 ± 0.0328	23.60
Supplementary series	35	-0.7684 ± 0.0467	16.45
Both series	103	-0.7852 ± 0.0255	30.79

Now $w_1=m_1+x_1$, $w_2=m_2+x_2$, ... , where x denotes the amount of non-active substances which can not contribute to the total metabolism. The ratios $\frac{h}{w}$ will be influenced by m and x to an extent proportional to their respective values. Since in the later stages of growth of the vertebrate organism there is a continuous increase in the amount

[68] In passing, it may be noted that there is another objection to these data. The differences in size are in part due to differences in age. Statements in regard to this factor are not explicit in all cases. The smaller animals were those which produced the most heat, both per unit of weight and per unit of surface. But the smaller animals are probably on the whole younger animals and, as pointed out in the chapter on age, there is (in man at least) a decline in the rate of metabolism during the later periods of growth.

of the inert tissue, and since the increase in weight subsequent to maturity is largely dependent upon the deposition of fat, it is quite clear that in a series of individuals of the same species the metabolism per kilogram of body-weight should decrease as the body-weight increases. Metabolism as measured in units of body-weight decreases as body-weight increases. That metabolism as measured in units of body-surface decreases at a lower rate is perhaps attributable merely to the fact that the values of $x^{\frac{2}{3}}$ increases less rapidly than x.

This type of relationship has long been familiar to statisticians. If we correlate between x and y/x we get a negative relationship which has been designated as a spurious correlation between indices.[69] The relationship may be easily demonstrated on our own data. In table 51 we have given the correlation between body-weight and heat-production in calories per kilogram of body-weight for certain of our series. The coefficients are negative and of a rather large size throughout.

5. STATISTICAL TESTS OF RELATIVE VALUE OF THE MEEH FORMULA AND OF THE DU BOIS HEIGHT-WEIGHT CHART.

From table 50 the reader may have noted that without exception the Du Bois height-weight chart gives a lower percentage variability for body-surface than does the Meeh formula. This point brings up the question of the relative value of these two measures of body-surface. Quite incidentally to carrying out the calculations for this chapter, we have been able to secure certain statistical tests of the relative value of the Meeh formula and of the Du Bois height-weight chart; it therefore seems desirable to insert these data in this place, after which we shall return to the discussion of our main problem of the validity of the body-surface law as applied to human individuals.

There are two distinct sources of error in the Meeh formula. First, the validity of the use of $\sqrt[3]{w^2}$ as a measure of the surface-area of different bodies rests on the two assumptions (*a*) that the two bodies have the same specific gravity, and (*b*) that they are comparable in form. Neither of these assumptions can be considered strictly valid when applied to men and women of different weights. The specific gravity of a very fat individual is certainly sensibly different from that of a lean one. The relative proportions of length of trunk and of leg differ according to the stature of the individual.[70] Finally a study of profile photographs of very fat and very lean individuals should suffice to convince any one that as far as form is concerned the two extremes can not be regarded as "comparable solids." Secondly, the constant factor of the Meeh formula is determined empirically. It carries with it, therefore, both the errors of measurement and the probable errors of random sampling attaching to any direct measurements of variable

[69] Pearson, Proc. Roy. Soc. Lond., 1897, 60, p. 492.
[70] Harris, unpublished constants.

quantities. The extent of error due to this source has been indicated on page 144 above.

We agree with the fundamental correctness of the statement of Du Bois and Du Bois [71] that "In any discussion as to whether metabolism is proportional to body-weight or to surface-area it is essential to apply a method of measuring the surface which does not depend entirely on weight."

A comparison of the correlation between body-weight and body-surface as determined by the two formulas will throw some further light upon the value of the two methods of estimating body-surface.

TABLE 52.—*Comparison of relations between weight and body-surface by the Meeh formula with the correlations between weight and body-surface by the Du Bois height-weight chart.*

Series.	N	Correlation between weight and body-surface by Meeh formula. r_{wa_M}	Correlation between weight and body-surface by height-weight chart r_{wa_D}	Differences $r_{wa_D}-r_{wa_M}$
Men.				
Original series:				
Athletes	16	0.9993±0.0002	0.9629±0.0123	−0.0364±0.0123
Others	62	0.9996±0.0001	0.9275±0.0120	−0.0721±0.0120
Whole series	89	0.9986±0.0002	0.9466±0.0074	−0.0520±0.0074
Gephart and Du Bois selection	72	0.9996±0.0001	0.9577±0.0066	−0.0419±0.0066
First supplementary series	28	0.9957±0.0011	0.9618±0.0095	−0.0339±0.0096
Original and first supplementary series	117	0.9988±0.0001	0 9495±0.0061	−0.0493±0.0061
Second supplementary series	19	0.9994±0.0002	0.9632±0.0112	−0.0362±0.0112
All men of three series	136	0.9988±0.0001	0.9505±0.0056	−0.0483±0.0056
Women.				
Original series	68	0.9982±0.0003	0.9578±0.0067	−0.0404±0.0067
Supplementary series	35	0.9992±0.0002	0.9792±0.0047	−0.0200±0.0047
Both series	103	0.9989±0.0001	0.9683±0.0041	−0.0306±0.0041

From the constants in table 52, it appears that the correlations between body-weight and body-surface as determined by both methods are large, but that in each group of individuals the correlation between body-weight and body-surface as determined from the Du Bois height-weight chart is lower than that between body-weight and body-surface as determined by the Meeh formula. This must be taken as evidence for the greater value of the Du Bois height-weight chart, since it shows that the body-surface is less a function of body-weight than in the case of the Meeh formula.

6. CORRELATION AS A CRITERION OF THE VALIDITY OF THE BODY-SURFACE LAW.

Since it is clear that a mere comparison by inspection of the sets of constants for metabolism measured in calories per kilogram of body-

[71] Du Bois and Du Bois, Arch. Intern. Med., 1915, **15**, p. 880.

weight and in calories per square meter of body-surface, or even simpler tests of the relative variability of the two sets of measures, are quite inadequate as criteria for selecting the best method of correcting for the size of the individual, a detailed treatment of this question is in order.

In the past the physiologist has been seeking to determine whether metabolism is proportional to body-weight or to surface-area. The difficulty has lain in the fact that body-weight and body-surface area are correlated characters. If individuals varied in weight only, and not in physical configuration, body-surface would be given at once by $k \times \sqrt[3]{w^2}$. This is, indeed, the basis of the Lissauer and the Meeh formulas. Thus if heat-production be in any degree correlated with one of these physical measurements, it must be in some degree correlated with the other. The degree of correlation between metabolism and either of the physical measurements due to its correlation with the other will depend upon the intensity of the correlation between the two physical measurements.

Thus the problem of the physiologist is not so simple as has been suggested when it is said that he must determine "whether metabolism is proportional to body-weight or to surface-area." What he has to do is to determine whether it is *more nearly* proportional to body-surface or to body-weight.

The difficulty in doing this has not been due solely to the fact that large series of actual measurements of body-surface and metabolism have not been available, but also to the fact that the physiologist has had no means of comparing directly the degree of interdependence of body-weight measures and metabolism and body-surface measures and metabolism. Results expressed in calories per kilogram of body-weight are unquestionably better than those expressed in calories per individual irrespective of size for standard periods of time. Results expressed in calories per square meter of body-surface are also more nearly comparable from individual to individual than those expressed merely in number of calories per individual for the same standard periods of time. The fundamental question is: Are results expressed in calories per square meter of body-surface so constant from individual to individual as to justify the statement that heat-production per square meter of body-surface is a constant? Or, in other words, to justify the statement that it is a physiological law that organisms have a heat-production proportional to their body-surface?

Now the closeness of agreement of a series of figures which shall be demanded to justify their designation as representing a constant must depend, in the last analysis, upon the judgment of the workers in a particular field. Specifically, in the case of metabolism investigations, physiologists, not physical chemists or astronomers, must decide how great a variation in the number of calories per square meter of surface

may be regarded as due to uncontrollable experimental error and hence not be considered as invalidating the generalization that heat-production per square meter of body-surface is a constant.

While only the physiologist can determine the amount of variation allowable in the measures of heat-production per kilogram of body-weight or per square meter of body-surface, the statistician may furnish certain criteria of value in formulating the decisions. While the statistician as such can not pass judgment upon the question of the degree of consistency in a set of constants which must be demanded if they are to be regarded as the expression of a biological law, he can furnish absolute criteria of the degree of consistency. What is really needed, first of all, is a measure of the closeness of interdependence of the total calories of heat produced by an individual, under the selected standard conditions for measuring basal metabolism, and the other characteristics of the individual with which metabolism may be reasonably assumed to be bound up.

TABLE 53.—*Comparison of correlation between body-weight and total heat-production with the correlations between body-surface by the two formulas and total heat-production.*

Series.	N	Weight and total heat per 24 hours r_{wh}	Surface by Meeh formula and total heat $r_{a_M h}$	Difference $r_{a_M h}-r_{wh}$	Surface by height-weight chart and total heat $r_{a_D h}$	Difference $r_{a_D h}-r_{wh}$
Men.						
Original series:						
Athletes	16	0.9577 ± 0.0139	0.9551 ± 0.0148	−0.0026 ± 0.0203	0.9671 ± 0.0109	+0.0094 ± 0.0177
Others	62	0.6251 ± 0.0522	0.6311 ± 0.0515	+0.0060 ± 0.0733	0.6632 ± 0.0479	+0.0271 ± 0.0707
Whole series	89	0.8012 ± 0.0256	0.7997 ± 0.0257	−0.0015 ± 0.0363	0.8303 ± 0.0222	+0.0291 ± 0.0339
Gephart and Du Bois selection	72	0.7879 ± 0.0301	0.7896 ± 0.0299	+0.0017 ± 0.0424	0.7862 ± 0.0304	−0.0017 ± 0.0428
First supplementary series	28	0.8664 ± 0.0318	0.8747 ± 0.0299	+0.0083 ± 0.0436	0.8636 ± 0.0324	−0.0028 ± 0.0454
Original and first supplementary series	117	0.8175 ± 0.0207	0.8196 ± 0.0205	+0.0021 ± 0.0291	0.8383 ± 0.0185	+0.0208 ± 0.0278
Second supplementary series	19	0.5758 ± 0.1034	0.5772 ± 0.1032	+0.0014 ± 0.1460	0.6274 ± 0.0938	+0.0516 ± 0.1396
All men of three series	136	0.7960 ± 0.0212	0.7980 ± 0.0210	+0.0020 ± 0.0298	0.8196 ± 0.0190	+0.0236 ± 0.0285
Women.						
Original series	68	0.7575 ± 0.0348	0.7612 ± 0.0344	+0.0037 ± 0.0489	0.7438 ± 0.0365	−0.0137 ± 0.0504
Supplementary series	35	0.4536 ± 0.0906	0.4698 ± 0.0888	+0.0162 ± 0.1269	0.4789 ± 0.0878	+0.0253 ± 0.1262
Both series	103	0.6092 ± 0.0418	0.6170 ± 0.0412	+0.0078 ± 0.0587	0.6111 ± 0.0416	+0.0019 ± 0.0590

We now turn to a consideration of the problem of the selection of a suitable measure of the degree of interdependence between the physical character and metabolism. Following the discussion in the preceding chapter, we shall first consider the coefficient of correlation.[72]

If the direct measures of metabolism are far more closely correlated with body-surface than with any other physical measurements, it seems

[72] After the manuscript for this volume was practically completed a paper by Armsby, Fries, and Braman (Proc. Nat. Acad. Sci., 1918, 4, p. 1; Journ. Agric. Research, 1918, 13, p. 43) appeared in which the method of correlation here employed was used.

clear that body-surface is the best single factor for predicting basal metabolism. If heat-production shows approximately the same correlation with body-weight as with body-surface, the conclusion must be drawn that the two are of practically equal significance for estimating basal metabolism. If the correlation between body-surface and the measure of metabolism be actually smaller than that for other physical characters, it must be relegated to a minor place as a means of predicting metabolism.

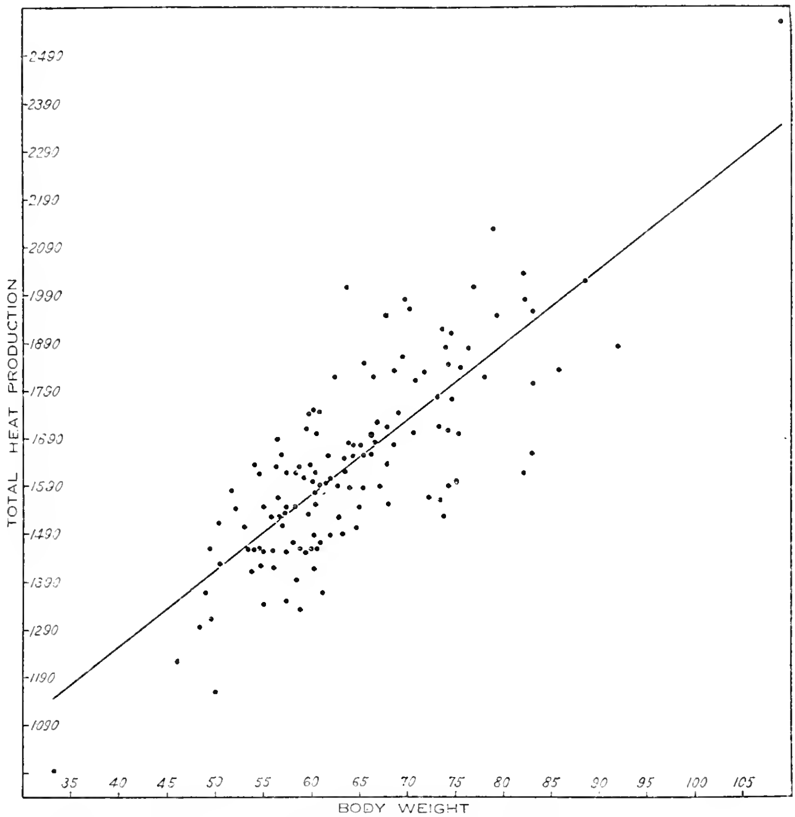

DIAGRAM 23.—Relationship between body-weight and daily heat-production by men.

The constants are arranged for a comparison of the correlations between weight and heat-production and surface and heat-production in table 53. The first problem which we have to consider on the basis of these constants is that of the existence of a physiological law. That total heat-production is related to body-weight and to body-surface is clearly shown by the constants. We doubt, however, whether such a quantitative law is what physiologists in general have had in mind when they have stated that heat-production is proportional to body-surface but not proportional to body-weight. Our constants show that

it is in some degree proportional to both body-surface and to body-weight and they furnish a measure of this closeness of agreement on a universally applicable scale of -1 to $+1$. They further show that the

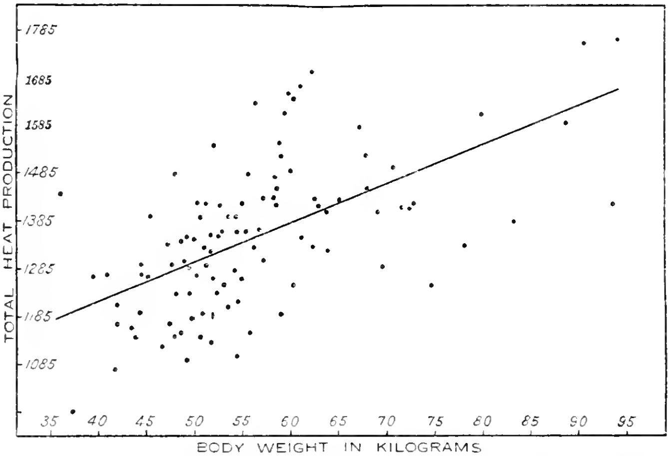

DIAGRAM 24.—Relationship between body-weight and total heat-production by women.

interrelationship is in no case a perfect one. We are not, therefore, dealing with a law in the sense that the term is used in the exact sciences.

Knowing the number of seconds which a body has been falling towards the earth, we can state its velocity at this moment or at any future moment of time. Knowing the volume of a gas at temperature t and pressure p, we can state its volume at temperature t' and pressure p'. These theoretical laws hold *in the individual instance* with as high a degree of precision as can be demonstrated by the most exact experimental method. Such is not the case in human metabolism. Instead of having a perfect correlation between body-weight and total heat-production, as we should if heat-production were proportional to body-weight, we have only about 80 per cent of perfect correlation.

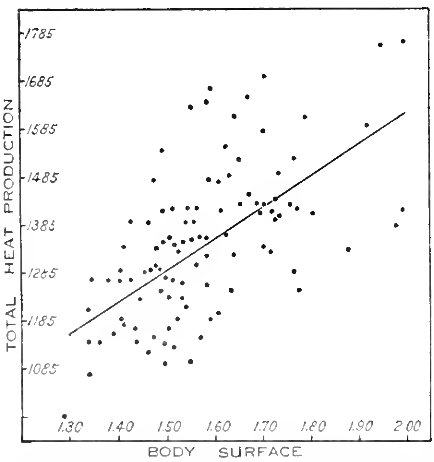

DIAGRAM 25.—Relationship between total heat-production and square meters of body-surface of women as estimated by the Du Bois height-weight chart.

The true significance of these correlations may be best understood by looking at them in a quite different way. If heat-production were actually proportional to body-weight, or to body-surface, we should

find a correlation of unity. For any given weight (or surface) there would then be only one possible heat-production. But as a matter of fact the coefficient of correlation, here being less than unity, shows that for any given body-weight or body-surface a variety of heat constants may be secured. How widely the heat-productions of individuals of sensibly identical body-weight may vary is well shown by diagram 23 for men and diagram 24 for women, in which each dot represents on

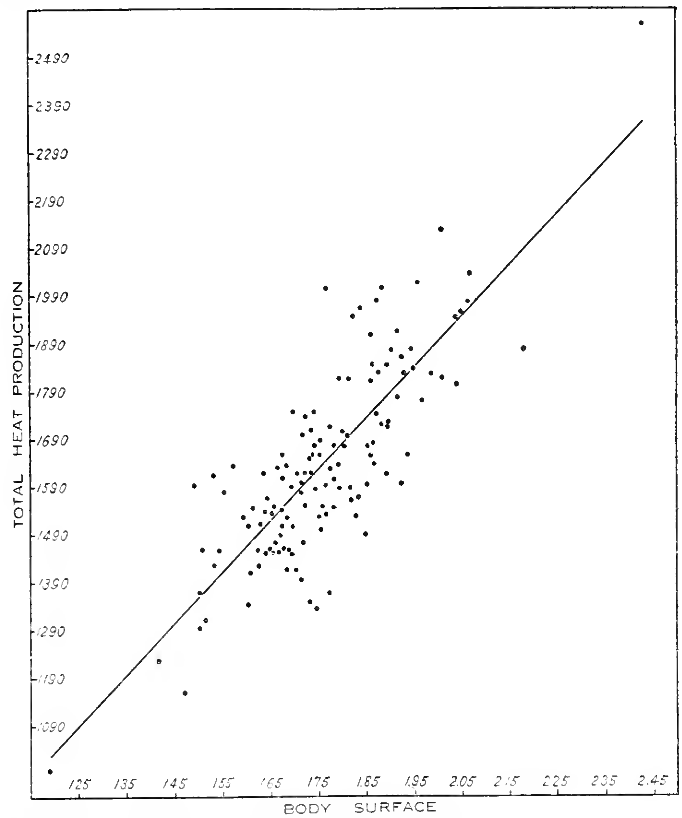

DIAGRAM 26.—Relationship between total heat-production and square meters of body-surface of men as estimated by the Du Bois height-weight chart.

the scale at the left the heat-production of an individual whose weight is given by the lower scale.[73] That body-surface is not much better than body-weight as a basis for prediction is evident from the wide scatter of the heat-productions for individuals of like superficial area in diagrams 25 and 26.

Now it is quite possible to determine from the correlation coefficient approximately the amount of variation which will be found on the average within the different weight or body-surface classes. This

[73] The straight lines in these diagrams are drawn from the equations in Chapter IV, p. 91.

variability of the subgroups defined by a given grade of weight or body-surface is given by

$$\sigma_{h_w} = \sigma_h \sqrt{1 - r_{wh}^2} \qquad \sigma_{h_a} = \sigma_h \sqrt{1 - r_{ah}^2}$$

where σ_h is the standard deviation of heat-production in individuals at large and σ_{h_w} and σ_{h_a} the standard deviation of heat-production in groups of individuals of the same weight or surface. The results for the major series are summarized in table 54.

TABLE 54.—*Percentage of the total variation in heat-production which remains after individuals are classified according to body-weight and body-surface by two formulas.*

Series.	Classified by body-weight.		Classified by Meeh formula.		Classified by height-weight chart.	
	Correlation r_{wh}	Percentage variability.	Correlation $r_{a_M h}$	Percentage variability.	Correlation $r_{a_D h}$	Percentage variability.
Men.						
Original series	0.801	59.84	0.799	60.04	0.830	55.73
Gephart and Du Bois selection	0.787	61.58	0.789	61.36	0.786	61.79
Original and first supplementary series	0.817	57.59	0.819	57.29	0.838	54.52
All men of three series	0.796	60.53	0.798	60.27	0.819	57.29
Women.						
Original series	0.757	65.28	0.761	64.85	0.743	66.84
Supplementary series	0.453	89.12	0.469	88.80	0.478	87.79
Both series	0.609	79.30	0.617	78.70	0.611	79.15

The entries in the body of this table show the relative amount of variation in metabolism which remains after individuals are sorted into groups according to body-weight or body-surface by the two formulas.[74] To facilitate comparison merely, the variabilities (standard deviations) of the subgroups of like weight or surface-area have been expressed as percentages of the standard deviation of heat-production in all individuals irrespective of body-weight or body-surface. A cursory inspection of the body of the table shows that the metabolism measurements for any given grade of body-weight or body-surface in the male series exhibit (roughly speaking) 55 or 60 per cent as much variation as measurements made on individuals irrespective of these characters, while in the female series they show from 65 to 90 per cent of the population variability.

We now turn to a consideration of the actual magnitudes of the correlations for body-weight and heat-production, r_{wh}, and body-surface area and heat-production, r_{ah}, as given in table 53.

Since body-surface is the character upon which such great emphasis has been laid as a standard in metabolism studies for the past quarter

[74] These are the theoretical values derived from the formulas just discussed. It is useless to compare them with the values computed directly when the number of individuals is so small as it is here.

of a century and more, it is important to make the comparisons between the results of different correlations in such a way as to show whether the surface area gives larger (*i.e.*, closer) correlations with total heat-production or other measures of metabolism than the other measures tested, or whether it gives sensibly the same or smaller values.

Our differences have, therefore, been taken (correlation for body-surface and measure of metabolism) *less* (correlation for other physical character and measure of metabolism). Thus, when the constant measuring the correlation for body-surface and a given measure of basal metabolism is larger than another constant with which it is compared, the difference is given the positive sign.

In men the correlation between body-surface by the Meeh formula and total heat per 24 hours is slightly higher in all but 2 cases (but in no case significantly higher) than that between body-weight and total heat-production. In women the correlation between surface as estimated by the Meeh formula and total heat is in all 3 series slightly but not significantly higher than that between body-weight and total heat-production.

Taking these constants as they stand they indicate, therefore, that body-weight gives practically as good a basis of prediction for heat-production as does body-surface by the Meeh formula. To this point we shall return later.

When the Du Bois height-weight chart is used the differences are not so regular. In 8 cases the chart measures of body-surface give the higher correlation, whereas in 3 cases the weight gives the higher correlation. Thus apparently surface as estimated by the Du Bois height-weight chart furnishes a better corrective measure than weight. Since the differences between r_{wh} and r_{ah} are in no case significant in comparison with their probable errors, one can not assert on the basis of the individual series that there is an actually significant physiological difference in the relationships between these two physical measurements and metabolism. The fact that the majority of the series indicate closer correlation of body-surface and total heat-production is evidence in favor of its closer correlation with total metabolism.

After the constants in table 53 were computed, Armsby, Fries, and Braman [75] published correlations for body-weight and total heat-production and body-surface as estimated by the Meeh formula and total heat-production for the constants published by Benedict, Emmes, Roth, and Smith [76] and by Means.[77] They find:

	r_{wh}	$r_{a_M h}$
For 98 men	0.7263 ± 0.0320	0.7747 ± 0.0272
For 75 women	0.7759 ± 0.0310	0.7447 ± 0.0347

[75] Armsby, Fries, and Braman, Proc. Nat. Acad. Sci., 1918, **4**, p. 3; Journ. Agric. Research, 1918, **13**, pp. 50–51.

[76] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139.

[77] Means, Journ. Biol. Chem., 1915, **21**, p. 263.

From these results they conclude that the constants "fail to show any greater correlation with the body-surface as computed by the Meeh formula than with the body-weight."

Notwithstanding this clear evidence against the body-surface law as applied to the individuals of the same species, Armsby, Fries, and Braman conclude[78] that their assemblage of data for man, cattle, hogs, and horses "tend to confirm the conclusions of E. Voit, that the basal katabolism of different species of animals is substantially proportional to their body surface."

Total heat which is used as the final expression of basal metabolism may be either directly or indirectly determined. In the case of indirect calorimetry it is calculated from the total amounts of CO_2 or O_2, taking into account the calorific value of the gas which varies with the respiratory quotient, *i.e.*, the ratio CO_2/O_2.

TABLE 55.—*Comparison of correlation between body-weight and oxygen-consumption with the correlations between body-surface by the two formulas and oxygen-consumption.*

Series.	N	Surface by Meeh formula and oxygen consumption $r_{a_M o}$	Difference $r_{a_M o}-r_{wo}$	Surface by Du Bois height-weight chart and oxygen consumption $r_{a_D o}$	Difference $r_{a_D o}-r_{wo}$
Men.					
Original series:					
Athletes	16	0.9574±0.0141	−0.0021±0.0195	0.9661±0.0112	+0.0066±0.0175
Others	62	0.6312±0.0515	+0.0057±0.0733	0.6647±0.0478	+0.0392±0.0707
Whole series	89	0.7997±0.0258	−0.0010±0.0364	0.8294±0.0223	+0.0287±0.0340
Gephart and Du Bois selection	72	0.7845±0.0306	+0.0016±0.0434	0.7838±0.0306	+0.0009±0.0434
First supplementary series	28	0.8777±0.0293	+0.0058±0.0424	0.8632±0.0325	−0.0087±0.0446
Original and first supplementary series	117	0.8207±0.0204	+0.0028±0.0290	0.8386±0.0185	+0.0207±0.0277
Second supplementary series	19	0.5771±0.1032	−0.0008±0.1459	0.6369±0.0919	+0.0590±0.1381
All men of three series	136	0.7978±0.0210	+0.0023±0.0298	0.8196±0.0190	+0.0241±0.0285
Women.					
Original series	68	0.7534±0.0354	+0.0026±0.0503	0.7355±0.0375	−0.0153±0.0518
Supplementary series	35	0.4741±0.0884	+0.0158±0.1262	0.4836±0.0873	+0.0253±0.1255
Both series	103	0.6019±0.0424	+0.0069±0.0608	0.5972±0.0428	+0.0022±0.0608

We turn, therefore, to a consideration of the correlations between body-weight and oxygen consumption and carbon-dioxide production in comparison with those for the two measures of body-surface and oxygen consumption and carbon-dioxide production. The results are given for oxygen consumption in table 55 and for carbon-dioxide output in table 56. The value of r_{wo} and r_{wc} are taken from table 24.

While the differences in the correlations are very small a great majority are positive in sign, *i.e.*, they indicate that the correlations for surface-area and metabolism are higher than those for weight and metabolism. Thus these results seem to indicate that body-surface

[78] Armsby, Fries, and Braman, Proc. Nat. Acad. Sci., 1918, **4**, p. 3–4.

gives a slightly better criterion of total heat-production than does body-weight.

We shall now approach the problem from a somewhat different angle.

7. THE PREDICTION-VALUE OF BODY-WEIGHT AND BODY-SURFACE.

When the physiologist asserts that heat-production is proportional to body-surface he states that knowing the body-surface of an individual we also know his basal metabolism. Of course there are tacitly assumed reservations. Pathological factors, the differentiation due to sex, and a number of other as yet intangible influences are supposed to be neglected. Nevertheless it must be admitted that if the assertion that heat-production is proportional to body-surface is of any practical significance, it is tantamount to the assertion that knowing the body-surface of the individual we have the best possible index of his basal metabolism.

TABLE 56.—*Comparison of the correlation between body-weight and carbon-dioxide production with correlations between body-surface by the two formulas and carbon-dioxide production.*

Series.	N	Surface by Meeh formula and carbon-dioxide production $r_{a_M c}$	Difference $r_{a_M c}-r_{wc}$	Surface by Du Bois height-weight chart and carbon-dioxide production $r_{a_D c}$	Difference $r_{a_D c}-r_{wc}$
Men.					
Original series:					
Athletes	15	0.9295±0.0236	−0.0059±0.0321	0.9378±0.0144	+0.0024±0.0260
Others	62	0.5807±0.0570	+0.0066±0.0809	0.6047±0.0543	+0.0306±0.0790
Whole series	88	0.7703±0.0292	−0.0033±0.0410	0.8043±0.0254	+0.0307±0.0384
Gephart and Du Bois selection	71	0.7687±0.0327	+0.0017±0.0464	0.7589±0.0339	−0.0081±0.0472
First supplementary series	28	0.8187±0.0420	+0.0121±0.0612	0.8283±0.0400	+0.0217±0.0598
Original and first supplementary series	116	0.7808±0.0244	−0.0003±0.0345	0.8024±0.0223	+0.0213±0.0331
Second supplementary series	19	0.5128±0.1140	+0.0086±0.1622	0.5240±0.1123	+0.0198±0.1610
All men of three series	135	0.7582±0.0247	+0.0007±0.0349	0.7884±0.0229	+0.0309±0.0337
Women.					
Original series	66	0.7392±0.0376	+0.0060±0.0537	0.7386±0.0377	+0.0054±0.0538
Supplementary series	35	0.4427±0.0917	+0.0176±0.1309	0.4503±0.0909	+0.0252±0.1303
Both series	101	0.6366±0.0399	+0.0100±0.0571	0.6357±0.0399	+0.0091±0.0571

We shall start out from the assumption that the best measure of the heat-production of an individual is that which gives the best prediction for an unknown series. Concretely, suppose that we predict the total heat-production of a series of individual men under standard conditions by three different methods. Surely it seems reasonable to regard the method *which predicts the metabolism of the individuals most exactly* as the *best* measure. Otherwise the whole contention for normal control series for use in pathological research or in other fields of practical nutrition work is stultified.

We shall, therefore, predict the daily heat-production of a series

of individuals of given weight, of given body-surface as approximated by the Meeh formula, and of given body-surface as estimated by the Du Bois height-weight chart, and shall determine which of these measures actually permits the closest prediction in the case of subjects whose metabolism is unknown so far as the development of the prediction formulas is concerned. The arithmetical routine is illustrated in tables 57–59, to be discussed below.

To avoid all criticism concerning the selection of measurements to be used as the fundamental series, we shall take those for the 72 individuals chosen by Gephart and Du Bois, and designated in this volume as the Gephart and Du Bois selection. From equations based upon this series we shall compute the total heat-production which should be found in individuals of three other series and compare the results of predicting these values by three different methods with the metabolism constants actually found.

The individuals used for the test series are in no case included in the series upon which the prediction formulas are based. The grouping of the individuals has been determined by factors which are entirely beyond our present control. The groups were selected before the prediction equations were calculated, and no change has been made subsequently.

The following groups have been used. (*a*) The 17 men rejected by Gephart and Du Bois from the 89 published by Benedict, Emmes, Roth, and Smith. (*b*) The first supplementary series of 28 men. (*c*) The second supplementary series of 19 men.

Thus it is possible to test the results of prediction in three separate series of men and (upon the combination of these series) on a general series of 64 individuals. Now all students of metabolism might not agree fully with Gephart and Du Bois in their selection of the 72 individuals as a basis for metabolism constants. It seems worth while, therefore, to base prediction formulas on a quite different series and to compare the predicted values of the metabolism of the 72 individuals of the Gephart and Du Bois selection with their actually determined heat-production. Such a procedure has not merely the merit of furnishing a more stringent criterion of the value of the various methods of calculating check series, but has the advantage of emphasizing in a clear-cut manner the fact that data are still inadequate for the most advantageous selection of control values for use in clinical calorimetry.

The most natural procedure is, of course, to base prediction formulas on the 64 individuals *not included in the Gephart and DuBois selection* and to test the results secured by these formulas against the observed values for the individuals of the Gephart and Du Bois selection.

These series of comparisons cover only men. Turning to women, it has seemed desirable to predict the results for the supplementary

series of 35 from the original series of 68 women, and in turn to predict the heat-production of the original series from constants or equations based on the supplementary series. Thus a very comprehensive test of the validity of the different methods of forming check series is secured.

Two methods of calculating the metabolism of an individual whose actual heat-production is unknown suggest themselves.

First, one may merely multiply the body-weight or body-surface of the subject by the average heat-production per unit of weight or per unit of surface in the standard series. This has been the method hitherto employed in the calculation of the control values to be used in clinical calorimetry.

Second, one may use a mathematical prediction equation based on the standard series. So far as we are aware, this method has not hitherto been employed in studies on basal metabolism.

While the second method seems the more logical of the two, we shall give the results of both.

When prediction of the heat-production of an individual is made by either of the methods a value is obtained which may be identical with the actually determined constant, but which in general deviates somewhat from it. Deviation may, therefore, be either positive or negative in sign. We shall, in consequence, have to consider whether the predictions made by a given method are on the whole too large or too small. Since we are in this case testing methods of prediction against actual observation, we have taken the differences (calculated heat-production) *less* (actually determined heat-production). Thus when a given prediction method gives results which are on the average too high, the mean deviation (with regard to sign) of the calculated from the actual heat-production will have the positive sign. When it is too low, it will have the negative sign. Dividing the sum of the deviations *with regard to sign* by the total number of individuals in the series in hand we have a measure of the average deviation in the direction of too high or too low prediction.

But the question as to whether a given prediction method gives on the whole too high or too low values is not the only one to be answered. One wishes to know the extent of deviations both above and below the observed value in the case of each of the methods used. One measure of such deviation is obtained by ignoring the signs and simply regarding a difference between observed and predicted values as an error of a given magnitude. Dividing the sum of these errors for the whole series by the number of individuals in the series, we have, in terms of *average deviation without regard to sign*, a measure of the relative precision of the different methods of prediction employed. This method has two disadvantages. First, it does violence to sound mathematical usage with regard to signs. Second, it gives the deviations

weight proportional to their magnitudes. But one may consider that very great deviations should be given proportionally more weight in testing different prediction methods than very slight deviations. The magnitudes of the deviations may be logically weighted and the transgression against the law of signs avoided by squaring the deviations before they are summed. The square root of the mean of these summed squares will then furnish a logical measure of the deviation of the calculated from the observed productions. For the sake of completeness in the investigation of a problem which has the controversial status of the "body-surface law" we shall use both of these methods.

The deviations of the predicted from the actually determined heat-production is expressed in two different ways in the accompanying tables: (1) The differences are expressed in the absolute terms of calories per 24 hours. (2) The differences are reduced to a relative basis by expressing them as a percentage of the mean heat-production in calories per 24 hours of the specific group of individuals dealt with.

We now turn to the actual data.

The average heat-productions for the 72 individuals of the Gephart and Du Bois selection and for the 64 other individuals for the three units of body-measurements adopted are as follows:

Heat-production per kilogram of body-weight:	
72 of Gephart and Du Bois selection	25.7944 ± 0.1655 calories.
64 others	25.5875 ± 0.2292 calories.
Difference	0.2069 ± 0.2827 calories.
Heat-production per square meter of body-surface by Meeh formula:	
72 of Gephart and Du Bois selection	831.639 ± 4.413 calories.
64 others	828.203 ± 5.742 calories.
Difference	3.436 ± 7.242 calories.
Heat-production per square meter of body-surface by Du Bois height-weight chart:	
72 of Gephart and Du Bois selection	926.653 ± 4.975 calories.
64 others	924.141 ± 6.063 calories.
Difference	2.512 ± 7.843 calories.

While the results for the two sets of individuals are not exactly identical, as shown by the differences, the probable errors of these differences show that the two groups of men can not be considered to differ significantly. Thus, while the constants of these two series will not give exactly identical results if used for the calculation of control values as a basis of comparison in applied calorimetry, the differences between them are so small that they can not be asserted to have any physiological significance.

The results for the two series of women are:

Heat-production per kilogram of body-weight:	
68 Original women	25.3500 ± 0.2467 calories.
35 Supplementary women	22.7229 ± 0.4103 calories.
Difference	2.6271 ± 0.4788 calories.

Heat-production per square meter of body-surface by Meeh formula:
68 Original women . . . . 772.397 ± 5.184 calories.
35 Supplementary women . . . . 715.057 ± 10.004 calories.
Difference . . . . 57.340 ± 11.267 calories.

Heat-production per square meter of body-surface by Du Bois height-weight chart:
68 Original women . . . . 865.324 ± 5.317 calories.
35 Supplementary women . . . . 820.257 ± 10.410 calories.
Difference . . . . 45.067 ± 11.690 calories.

The agreement of the *means* for the two series of women is not as good as that for the two series of men. Possibly this is partly due to the fact that the larger female series has only about as many individuals as the smaller male series, while the smaller female series comprises only about half as many individuals as the smaller of the two male series. Whatever the cause of the difference in the two female series, the consequence must necessarily be a larger error of prediction than in the case of males.

TABLE 57.—*Comparison of actual heat-production and heat-production calculated (a) from the mean heat per kilogram of body-weight and (b) from the equation for the regression of total heat on body-weight in the Gephart and Du Bois selection.*

Individual.	Body-weight.	Measured heat-production.	Calculated from mean.		Calculated from equation.	
			Heat.	Difference.	Heat.	Difference.
H. F.	82.1	1615	2118	+503	1937	+322
Prof. C.	83.0	1655	2141	+486	1952	+297
W. S.	88.5	2017	2283	+266	2044	+ 27
O. F. M.	85.8	1827	2213	+386	1999	+172
M. H. K.	79.0	1944	2038	+ 94	1885	− 59
H. W.	108.9	2559	2809	+250	2385	−174
F. A. R.	74.4	1704	1919	+215	1808	+104
F. E. M.	75.0	1698	1935	+237	1818	+120
R. I. C.	56.8	1687	1465	−222	1514	−173
W. W. C.	56.3	1629	1452	−177	1506	−123
L. D. A.	57.1	1539	1473	− 66	1519	− 20
F. M. M.	59.7	1739	1540	−199	1563	−176
E. J. W.	50.0	1158	1290	+132	1401	+243
F. P.	49.3	1591	1272	−319	1389	−202
V. G.	54.3	1632	1401	−231	1473	−159
C. H. H.	55.1	1421	1421	±000	1486	+ 65
B. N. C.	50.6	1510	1305	−205	1411	− 99

Multiplying body-weight and body-surface by the two formulas by these values, we obtain the predicted values. Upon a comparison of the computed values with those obtained by actual measurement, we may base our conclusions concerning the relative merit of various methods of prediction.

The arithmetical routine is naturally somewhat extensive. It will be illustrated for only the smallest series—the 17 men omitted by Gephart and Du Bois from the original Nutrition Laboratory series. The actual and calculated values and their differences are given for the individual subjects in the third, fourth, and fifth sections of tables 57–59.

TABLE 58.—*Comparison of actual heat-production and heat-production calculated (a) from the mean heat per square meter of body-surface by the Meeh formula and (b) from the equation for the regression of total heat on body-surface by the Meeh formula in the Gephart and Du Bois selection.*

Individual.	Body-surface by Meeh formula.	Measured heat-production.	Calculated from mean.		Calculated from equation.	
			Heat.	Difference.	Heat.	Difference.
H. F.	2.33	1615	1938	+323	1934	+319
Prof. C.	2.34	1655	1946	+291	1942	+287
W. S.	2.45	2017	2038	+ 21	2032	+ 15
O. F. M.	2.40	1827	1996	+169	1991	+164
M. H. K.	2.27	1944	1888	− 56	1884	− 60
H. W.	2.81	2559	2337	−222	2328	−231
F. A. R.	2.18	1704	1813	+109	1810	+106
F. E. M	2.19	1698	1821	+123	1819	+121
R. I. C	1.82	1687	1514	−173	1515	−172
W. W. C	1.81	1629	1505	−124	1506	−123
L. D. A.	1.83	1539	1522	− 17	1523	− 16
F. M. M.	1.88	1739	1563	−176	1564	−175
E. J. W.	1.67	1158	1389	+231	1391	+233
F. P.	1.66	1591	1381	−210	1383	−208
V. G.	1.77	1632	1472	−160	1474	−158
C. H. H	1.78	1421	1480	+ 59	1482	+ 61
B. N. C.	1.69	1510	1405	−105	1408	−102

TABLE 59.—*Comparison of actual heat-production and heat-production calculated (a) from the mean heat per square meter of body-surface by the Du Bois height-weight chart and (b) from the equation for the regression of total heat on body-surface by the Du Bois height-weight chart in the Gephart and Du Bois selection.*

Individual.	Body-surface by Du Bois height-weight chart.	Measured heat-production.	Calculated from mean.		Calculated from equation.	
			Heat.	Difference.	Heat.	Difference.
H. F.	1.90	1615	1761	+146	1774	+159
Prof. C.	1.93	1655	1788	+133	1805	+150
W. S.	1.96	2017	1816	−201	1836	−181
O. F. M	1.98	1827	1835	+ 8	1856	+ 29
M. H. K.	2.04	1944	1890	− 54	1918	− 26
H. W.	2.43	2559	2252	−307	2318	−241
F. A. R.	1.80	1704	1668	− 36	1672	− 32
F. E. M	1.81	1698	1677	− 21	1682	− 16
R. I. C.	1.76	1687	1631	− 56	1631	− 56
W. W. C.	1.67	1629	1548	− 81	1538	− 91
L. D. A.	1.67	1539	1548	+ 9	1538	− 1
F. M. M.	1.72	1739	1594	−145	1590	−149
E. J. W.	1.47	1158	1362	+204	1333	+175
F. P.	1.50	1591	1390	−201	1364	−227
V. G.	1.57	1632	1455	−177	1436	−196
C. H. H	1.62	1421	1501	+ 80	1487	+ 66
B. N. C.	1.63	1510	1510	±000	1497	− 13

The average deviation *with regard to sign* of the calculated from the observed values are given in table 60. These show that in all series except one the values predicted from the Gephart and Du Bois selection average somewhat too high. The prediction of the value of the metab-

olism of the Gephart and Du Bois selection from the means for the 64 other men is for each method somewhat too low. Similarly, in dealing with women we note that the values predicted for the supplementary series from the original female series are on the average too high, while those predicted for the original series are on the average too low.

Such differences in sign are of course a necessary result of the differences in the constants of the two standard series of each sex. The point will receive further consideration below.

In prediction from the Gephart and Du Bois selection, the average deviation with regard to sign given by using the mean metabolism

Table 60.—*Average deviation with regard to sign of total heat-production as predicted by mean heat-production per unit of body-weight or surface in standard series from the actual heat-production.*

Series	*N*	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Averages based on Gephart and Du Bois selection:				
I. First supplementary series	28	+ 11.8 = 0.74 p. ct.	+ 6.5 = 0.40 p. ct.	+25.0 = 1.56 p. ct.
II. Second supplementary series	19	+ 38.3 = 2.34 p. ct.	+ 14.6 = 0.89 p. ct.	+ 4.7 = 0.29 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	+ 67.6 = 3.97 p. ct.	+ 4.9 = 0.29 p. ct.	−41.1 = 2.42 p. ct.
IV. All individuals	64	+ 34.5 = 2.10 p. ct.	+ 8.5 = 0.52 p. ct.	+ 1.4 = 0.09 p. ct.
Averages based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	− 3.0 = 0.18 p. ct.	− 6.5 = 0.40 p. ct.	− 3.5 = 0.22 p. ct.
Women.				
Averages based on original series:				
VI. Supplementary series	35	+191.7 = 14.32 p. ct.	+119.0 = 8.89 p. ct.	+77.9 = 5.82 p. ct.
Averages based on supplementary series:				
VII. Original series	68	−116.6 = 8.61 p. ct.	− 93.9 = 6.93 p. ct.	−69.9 = 5.16 p. ct.

per square meter of body-surface as calculated by the Du Bois height-weight chart is less than that given by the use of the mean metabolism per kilogram of body-weight in every case except the first supplementary series. The total series of 64 individuals shows an average plus deviation of only 1.4 calories per day by the Du Bois height-weight chart, of 8.5 calories by the Meeh formula, and of 34.5 calories by body-weight.

In predicting the values of the 72 individuals from the means based on the 64 other men, the Du Bois height-weight chart gives better results for deviation with regard to sign than does the Meeh surface formula, but slightly worse results than prediction from body-weight. In predicting the total heat-production in the two female series, the Du Bois height-weight chart gives much smaller deviations than either of the other methods. Apparently, therefore, the Du Bois height-weight chart gives the smallest average deviation *above or below* the

ideal zero deviation, and so far as this test is concerned must accordingly be regarded as furnishing the best basis for predicting the metabolism of an unknown subject.

Turn now to the average deviations without regard to sign. These show the average error either above or below the actually observed values. The averages are given in table 61. For the whole series of 64 individuals in which prediction is based on the averages per unit in the Gephart and Du Bois selection [79] the average error is 100 calories by the Du Bois height-weight chart as compared with 141 calories by body-weight, or 6.08 per cent as compared with 8.57 per cent of the average heat-production of the individuals tested. In predicting the

TABLE 61.—*Average deviation without regard to sign of total heat-production as predicted from the mean heat-production per unit of body-weight or surface in standard series from the actual heat-production.*

Series.	*N*	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Averages based on Gephart and Du Bois selection:				
I. First supplementary series	28	92.8 = 5.78 p. ct.	86.8 = 5.40 p. ct.	94.1 = 5.86 p. ct.
II. Second supplementary series	19	127.0 = 7.75 p. ct.	90.5 = 5.52 p. ct.	99.7 = 6.08 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	234.6 = 13.79 p. ct.	151.1 = 8.88 p. ct.	109.4 = 6.43 p. ct.
IV. All individuals	64	140.6 = 8.57 p. ct.	105.0 = 6.40 p. ct.	99.8 = 6.08 p. ct.
Averages based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	106.4 = 6.55 p. ct.	86.9 = 5.35 p. ct.	88.7 = 5.46 p. ct.
Women.				
Averages based on original series:				
VI. Supplementary series	35	243.7 = 18.21 p. ct.	178.4 = 13.33 p. ct.	149.9 = 11.20 p. ct.
Averages based on supplementary series:				
VII. Original series	68	169.8 = 12.53 p. ct.	115.4 = 8.52 p. ct.	94.6 = 6.98 p. ct.

metabolism of the 72 individuals of the Gephart and Du Bois selection from averages based on the 64 other individuals, the average deviations range from 87 to 106 calories, or 5.35 per cent for surface by the Meeh formula, 5.46 per cent for surface by the Du Bois height-weight chart, and 6.55 per cent for body-weight. Errors are much larger in the female series, ranging from 6.98 per cent to 18.21 per cent, but with the order of errors always lowest for prediction from body-surface by the Du Bois height-weight chart, highest by body-weight, and intermediate in

[79] In working with the subgroups great irregularity must be expected because of the limited numbers of individuals. In the case of the 17 individuals discarded from the original Nutrition Laboratory series by Gephart and Du Bois the results of predicting from body-weight are particularly bad. The error is 6.43 per cent in the case of the height-weight chart and 13.79 per cent in the case of body-weight. In the first supplementary series prediction from body-weight gives slightly greater error than prediction from body-surface by the Meeh formula, but slightly less error than prediction from the Du Bois height-weight chart. In all other series the error by the height-weight chart is considerably less than by the body-weight method, and in all but two cases it is less than prediction by the use of means for heat-production per unit of surface-area by the Meeh formula.

prediction from area by the Meeh formula. Again the results indicate the superiority of the Du Bois height-weight chart as a basis of predicting the metabolism of an unknown.

Table 62 gives (in terms of the square root of mean-square deviation of the predicted from the actual values) a comparison of the results of predicting by the three different means. The square root of the mean-square deviation of the calculated from the actually measured metabolism is in all series greater in prediction from weight than it is in prediction from the height-weight chart. This method, like the two preceding, therefore, justifies the conclusion that (as an empirical basis for the prediction of the heat-production of an individual, *on the assumption that heat-production bears a definite ratio to some physical character*) the Du Bois height-weight chart measure of body-surface area furnishes distinctly better means of prediction than does body-weight. In the series of 64 individuals in which prediction is made from the Gephart and Du Bois selection the square root of mean square errors expressed as a percentage of the mean of the measured heat-production of the individuals stand as 11.5 : 7.8; in the Gephart and Du Bois selection they stand as 8.1 : 6.8; in the first female series as 14.9 : 9.0; and in the second female series as 24.5 : 13.0 per cent.

TABLE 62.—*Square root of mean-square deviation of total heat-production as predicted from the mean heat-production per unit of body-weight and surface in standard series from the actual heat-production.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Averages based on Gephart and Du Bois selection:				
I. First supplementary series	28	136.2 = 8.49 p. ct.	107.7 = 6.71 p. ct.	117.3 = 7.31 p. ct.
II. Second supplementary series	19	171.3 = 10.45 p. ct.	135.3 = 8.25 p. ct.	134.4 = 8.20 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	268.1 = 15.76 p. ct.	173.5 = 10.20 p. ct.	139.1 = 8.18 p. ct.
IV. All individuals	64	189.5 = 11.55 p. ct.	136.0 = 8.29 p. ct.	128.5 = 7.83 p. ct.
Averages based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	132.2 = 8.14 p. ct.	109.1 = 6.72 p. ct.	110.6 = 6.81 p. ct.
Women.				
Averages based on original series:				
VI. Supplementary series	35	327.8 = 24.49 p. ct.	218.7 = 16.34 p. ct.	174.0 = 13.00 p. ct.
Averages based on supplementary series:				
VII. Original series	68	201.1 = 14.85 p. ct.	142.0 = 10.48 p. ct.	122.1 = 9.01 p. ct.

We now turn to the prediction of metabolism by means of a mathematical equation fitted to a series of observations. Because of its simplicity and its direct relation to the correlation coefficient we have naturally first availed ourselves of the linear regression equation. These follow:

Equations based on 72 individuals chosen by Gephart and Du Bois:

For total heat on body-weight, $h = 565.390 + 16.707\, w$.

For total heat on body-surface by Meeh formula, $h = 19.463 + 821.567\, a_M$.

For total heat on body-surface by Du Bois height-weight chart,

$$h = -175.338 + 1026.173\, a_D.$$

Equations based on 64 men not included in the Gephart and Du Bois selection:

For total heat on body-weight, $h = 641.261 + 15.392\, w$.

For total heat on body-surface by Meeh formula, $h = 126.334 + 763.680\, a_M$.

For total heat on body-surface by Du Bois height-weight chart,

$$h = -310.884 + 1101.230\, a_D.$$

Equations based on 68 women of original Nutrition Laboratory series:

For total heat on body-weight, $h = 781.408 + 10.522\, w$.

For total heat on body-surface by Meeh formula, $h = 461.758 + 506.428\, a_M$.

For total heat on body-surface by Du Bois height-weight chart, $h = 88.493 + 808.401\, a_D$.

Equations based on the 35 supplementary women:

For total heat on body-weight, $h = 957.468 + 6.313\, w$.

For total heat on body-surface by Meeh formula, $h = 741.987 + 316.101\, a_M$.

For total heat on body-surface by the Du Bois height-weight chart,

$$h = 519.673 + 500.252\, a_D.$$

Again we may use the 17 individuals omitted by Gephart and Du Bois from the original Nutrition Laboratory series to illustrate the method of calculation. The values are given in the sixth and seventh columns of tables 57, 58, and 59. Space does not permit the publication of the calculated values and their deviation from the actually observed constants in the other series.

Before taking up the question of the relative precision of prediction of heat-production from equations based on body-weight and on body-surface by the two formulas, we may consider the relative closeness of prediction by means of average measures in the standard series and by means of equations. In doing this we shall draw the comparisons solely between the results of prediction from means alone and from equations for the same unit of bodily measurement.

In the tables, 63–65 the differences are given in calories per day and in percentages of the average heat-production of the group of individuals dealt with. The positive sign indicates that the prediction from means gives a larger error, the negative sign that it gives a smaller error than prediction by the use of the regression equation. In comparing the deviations with regard to sign it has been necessary to consider the magnitudes of the deviations only in these difference tables. The differences show, therefore, which method gives the numerically larger average error, but give no information concerning the sign of this error. The latter can, of course, be obtained from tables 60 and 66.

The differences between the average deviations with regard to sign in table 63 show that in 6 out of the 7 cases prediction by equations based on body-weight gives a smaller average deviation than prediction from mean heat-production per kilogram of body-weight. In the exceptional case the difference is very small (*i.e.*, 4.4 calories or 0.28 per cent), whereas in 5 of the 6 cases in which the differences are posi-

tive in sign they are also of a very material order of magnitude, ranging from 24.9 to 113.8 calories or from 1.51 to 8.50 per cent of the average heat-productions of the groups of individuals. In predictions involving body-surface as estimated by the Meeh formula the use of equations gives a smaller net deviation than computation of heat-production by considering it proportional to body-surface. The differences are not so large when measures of body-surface by the Du Bois height-weight chart are used, but here 4 out of the 7 comparisons indicate by the positive sign of the differences the superiority of the regression-line method of prediction.

TABLE 63.—*Differences in calories between the average deviations with regard to sign resulting from the use of means and straight-line equations for prediction.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Prediction from Gephart and Du Bois selection:				
I. First supplementary series	28	+ 4.3 = 0.27 p. ct.	+ 0.2 = 0.01 p. ct.	+ 0.2 = 0.02 p. ct.
II. Second supplementary series	19	+25.8 = 1.58 p. ct.	+ 0.5 = 0.03 p. ct.	− 1.4 = 0.08 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	+57.9 = 3.40 p. ct.	+ 1.3 = 0.08 p. ct.	+ 2.9 = 0.17 p. ct.
IV. All individuals	64	+24.9 = 1.51 p. ct.	+ 0.6 = 0.04 p. ct.	− 1.1 = 0.06 p. ct.
Prediction from 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	− 4.4 = 0.28 p. ct.	+ 0.4 = 0.02 p. ct.	− 0.6 = 0.03 p. ct.
Women.				
Prediction from original series:				
VI. Supplementary series	35	+113.8 = 8.50 p. ct.	+40.1 = 3.00 p. ct.	+ 4.7 = 0.35 p. ct.
Prediction from supplementary series:				
VII. Original series	68	+63.3 = 4.68 p. ct.	+38.6 = 2.85 p. ct.	+18.4 = 1.36 p. ct.

If we consider together all of the tests of prediction by equations as compared with prediction from the average values of metabolism per unit of body-weight or body-surface area made in table 63, we note that 17 out of the 21 differences are positive. In other words, prediction from the mean heat-production per unit in the standard series gives a larger average deviation with regard to sign than prediction from equations.

Turning now to comparison of the average deviations without regard to sign, we have the results set forth in table 64. The first column of constants shows the differences between the average deviations (without regard to sign) of the predicted from the actually observed heat-productions when the predictions are made by the use of equations and when they are made from the average heat-productions per unit of body-weight in the check series as a whole. The positive signs (indicating a greater error of prediction when average heat-production per kilogram of body-weight is used as a standard) show that the equations give better results in every instance.

In comparing the results of predicting total heat-production from body-surface by equations and by considering it proportional to the average heat-production per square meter of body-surface, we note that the differences are far smaller than those found when body-weight is used. It is not, therefore, so essential to use the equations when body-surface is to be employed as a basis of prediction as when body-weight is used. But in predicting from body-surface the equations give better results in 8 out of the 14 comparisons.

Table 65 gives the comparison of the square root of mean square deviation of the calculated from the actual values for the prediction by the use of means only and by the use of linear regression equations. In prediction from body-weight, the straight line gives far more satisfactory results. In the case of the two body-surface measurements there is less difference. It is important to note that in the case of the Du Bois height-weight chart, in which body-surface is not merely a function of weight, the evidence for accuracy of prediction is in favor of the linear prediction formula. This is shown by the fact that in 6 of the 7 cases prediction from the mean heat-production in the standard series gives a larger square root of mean square deviation than prediction by the use of linear equations.

TABLE 64.—*Differences in calories between the average deviations without regard to sign resulting from the use of means and straight-line equations for prediction.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Prediction from Gephart and Du Bois selection:				
I. First supplementary series	28	+ 1.7=0.11 p. ct.	− 0.7=0.05 p. ct.	+4.5=0.28 p. ct.
II. Second supplementary series	19	+27.6=1.69 p. ct.	− 9.5=0.58 p. ct.	−1.1=0.07 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	+85.5=5.03 p. ct.	+ 1.0=0.06 p. ct.	+3.0=0.18 p. ct.
IV. All individuals	64	+31.6=1.92 p. ct.	− 2.8=0.17 p. ct.	+2.4=0.14 p. ct.
Prediction from 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	+18.3=1.12 p. ct.	− 0.5=0.03 p. ct.	±0.0=0.00 p. ct.
Women.				
Prediction from original series:				
VI. Supplementary series	35	+93.7=7.00 p. ct.	+29.4=2.20 p. ct.	+3.8=0.28 p. ct.
Prediction from supplementary series:				
VII. Original series	68	+73.7=5.44 p. ct.	+19.9=1.47 p. ct.	+1.5=0.11 p. ct.

Taking all the three lines of evidence together, a material superiority of the linear regression equation over the method heretofore used for purposes of prediction is evident.

We now turn to a comparison of the results of predicting metabolism by means of straight-line equations based on body-weight and based on body-surface. We shall compare the results of such prediction

in three ways: by the determination of the mean error with regard to sign, by the determination of the mean error without regard to sign, and by the determination of the square root of mean square deviation of the predicted from the actually measured values.

The mean deviations with regard to sign appear in table 66. With one exception they indicate that in the nine comparisons with the three subseries (I-III) prediction from the constants of the Gephart and Du Bois selection is on the average too high. This is also true of the whole series of 64 individuals. The actual amount of the deviation is not large. It ranges from 3.6 to 38.2 calories in the subseries and from 2.5 to 9.6 calories in the combination series. In terms of percentages of the mean heat-production of the groups dealt with these

TABLE 65.—*Differences in calories between square root of the mean-square errors of prediction by use of means and by use of straight-line equations.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Prediction from Gephart and Du Bois selection:				
I. First supplementary series	28	+ 24.4 = 1.52 p. ct.	− 0.3 = 0.02 p. ct.	+3.4 = 0.21 p. ct.
II. Second supplementary series	19	+ 27.5 = 1.68 p. ct.	− 8.2 = 0.50 p. ct.	−0.5 = 0.03 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	+ 97.2 = 5.72 p. ct.	+ 0.9 = 0.06 p. ct.	+6.2 = 0.37 p. ct.
IV. All individuals	64	+ 50.3 = 3.06 p. ct.	− 2.3 = 0.14 p. ct.	+2.9 = 0.18 p. ct.
Prediction from 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	+ 22.0 = 1.35 p. ct.	− 0.4 = 0.03 p. ct.	+0.4 = 0.02 p. ct.
Women.				
Prediction from original series:				
VI. Supplementary series	35	+154.3 = 11.53 p. ct.	+46.9 = 3.50 p. ct.	+4.9 = 0.37 p. ct.
Prediction from supplementary series:				
VII. Original series	68	+ 80.9 = 5.98 p. ct.	+22.2 = 1.64 p. ct.	+1.7 = 0.12 p. ct.

average deviations with regard to sign range from 0.15 to 2.25 per cent, but only 2 of the subseries show a percentage deviation of over 1 per cent, and the 3 constants for the whole series of 64 individuals show a deviation of less than 0.6 per cent.

Since the constants based on the Gephart and Du Bois selection give slightly too high results when used to predict the heat-production of other individuals, it is necessary that the constants of this other series give values which are too low when they are used to predict the heat-production of the individuals of the Gephart and Du Bois selection. We note, therefore, that the average deviations for the predicted values of the Gephart and Du Bois selection are negative in sign throughout. The actual values are roughly comparable with those already considered, ranging from 4.1 to 7.4 calories, or from 0.25 to 0.46 per cent of the mean heat-production.

This difference in the sign of the average deviation in the two

series emphasizes the fact that even series comprising over 60 individuals each are not large enough to give wholly accurate mean predictions of metabolism. Metabolism constants are highly variable, and this has as a necessary consequence a high probable error of a mean constant based on a number of individuals which to the experimental physiologist would seem to be very large. The reader will of course note that since the average deviations of predicted values differ in sign in these two series, the result of combining the two series for the purpose of predicting standard control values, as we shall do later in this volume, will be an average deviation much more nearly the theoretical zero in amount. How close to the theoretical the average of values predicted from these combined series will lie can, of course, be determined only in the future when the necessary experimental data have been collected.

TABLE 66.—*Average deviation with regard to sign of total heat-production as predicted by linear equations from the actual heat-production.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart III.
Men.				
Equations based on Gephart and Du Bois selection:				
I. First supplementary series	28	+ 7.5 = 0.47 p. ct.	+ 6.3 = 0.39 p. ct.	+24.8 = 1.54 p. ct.
II. Second supplementary series	19	+12.5 = 0.76 p. ct.	+14.1 = 0.86 p. ct.	+ 6.1 = 0.37 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	+ 9.7 = 0.57 p. ct.	+ 3.6 = 0.21 p. ct.	−38.2 = 2.25 p. ct.
IV. All individuals	64	+ 9.6 = 0.58 p. ct.	+ 7.9 = 0.48 p. ct.	+ 2.5 = 0.15 p. ct.
Equations based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	− 7.4 = 0.46 p. ct.	− 6.1 = 0.38 p. ct.	− 4.1 = 0.25 p. ct.
Women.				
Equations based on original series:				
VI. Supplementary series	35	+77.9 = 5.82 p. ct.	+78.9 = 5.89 p. ct.	+73.2 = 5.47 p. ct.
Equations based on supplementary series:				
VII. Original series	68	−53.3 = 3.93 p. ct.	−55.3 = 4.08 p. ct.	−51.5 = 3.80 p. ct.

Comparable results, as far as the opposite signs are concerned, are found in the two feminine series. The magnitudes of the deviations are, however, much greater. We find, in fact, averages ranging from about 50 to about 80 calories, instead of from 2.5 to 9.6 calories, as in the general male series. Expressed in percentages of the mean, the deviations are of the order 3.8 to 5.9 per cent, instead of generally lower than 1 per cent. The conclusion to be drawn from this result is obvious. Prediction of the metabolism of women can not be carried out by these equations with the degree of certainty that is possible in dealing with men. To what extent this may be due to the smaller number of records of women as yet available, and to what extent it may be looked upon as due to age heterogeneity or as indicating real biological differences between the sexes, must remain a problem for further investigation and consideration.

Confining our attention to the four general series, IV–VII, in which the number of individuals is reasonably large, it is apparent that in every case prediction from the linear equations based on body-surface as determined by the Du Bois height-weight chart gives lower average deviations with regard to sign than do those based on either body-surface by the Meeh formula or body-weight. Thus the Du Bois height-weight chart gives the best prediction, in so far as accuracy of prediction can be measured by the average deviation of the predicted from the actually observed value. There seems to be little difference between the results of prediction from body-weight and from body-surface as estimated by the Meeh formula.

TABLE 67.—*Average deviation without regard to sign of total heat-production as predicted by linear equations from actual heat-production.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Equations based on Gephart and Du Bois selection:				
I. First supplementary series	28	91.1 = 5.67 p. ct.	87.5 = 5.45 p. ct.	89.6 = 5.58 p. ct.
II. Second supplementary series	19	99.4 = 6.06 p. ct.	100.0 = 6.10 p. ct.	100.8 = 6.15 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	149.1 = 8.76 p. ct.	150.1 = 8.82 p. ct.	106.4 = 6.25 p. ct.
IV. All individuals	64	109.0 = 6.64 p. ct.	107.8 = 6.57 p. ct.	97.4 = 5.93 p. ct.
Equations based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	88.1 = 5.43 p. ct.	87.4 = 5.38 p. ct.	88.7 = 5.46 p. ct.
Women.				
Equations based on original series:				
VI. Supplementary series	35	150.0 = 11.21 p. ct.	149.0 = 11.13 p. ct.	146.1 = 10.92 p. ct.
Equations based on supplementary series:				
VII. Original series	68	96.1 = 7.09 p. ct.	95.5 = 7.05 p. ct.	93.1 = 6.87 p. ct.

Turning to the average deviations without regard to sign, we note from table 67 that in the whole series of 64 individuals the three methods give deviations of only 109, 108, and 97 calories or stand in the ratio 6.64 : 6.57 : 5.93 per cent. Thus the difference in the percentage error of predicting from body-weight and body-surface by the Du Bois height-weight chart is only $6.64 - 5.93 = 0.71$ per cent.

For the 72 individuals of the Gephart and Du Bois selection the average deviations for the three methods of prediction are 88.1, 87.4, and 88.7 calories, or stand as 5.43 : 5.38 : 5.46 per cent. Thus body-weight is a little better than body-surface by the height-weight chart as a basis of prediction. In the two feminine series the absolute error in calories is considerably larger, the percentages ranging from 6.87 to 11.21. In both feminine series the Du Bois height-weight chart gives the lowest and body-weight the highest average deviation. The height-weight chart is therefore the best and body-weight the worst basis for prediction.

Turning to the square root of mean-square deviation as given in table 68 for our most critical test of the three methods, we find that for the first series of 64 men and for the supplementary series of women the Du Bois height-weight chart gives closer prediction than body-weight. The differences in terms of percentages of the mean heat-production of the groups dealt with are $8.48-7.65=0.83$ per cent for the men and $12.96-12.63=0.33$ per cent for the women.

In the Gephart and Du Bois selection, body-weight and body-surface by the Du Bois height-weight chart are equally good as a basis for prediction, differing by only $6.79-6.79=0.00\pm$ per cent. The original women also show practical identity in the results of the two methods of prediction, the difference being only $8.87-8.89=-0.02$ per cent.

TABLE 68.—*Square root of mean-square deviation of total heat-production as predicted by linear equations from the actual heat-production.*

Series.	N	Prediction from body-weight in kilograms. I.	Prediction from body-surface, Meeh formula. II.	Prediction from body-surface, height-weight chart. III.
Men.				
Equations based on Gephart and Du Bois selection:				
I. First supplementary series	28	111.8= 6.97 p. ct.	108.0= 6.73 p. ct.	113.9= 7.10 p. ct.
II. Second supplementary series	19	143.8= 8.77 p. ct.	143.5= 8.75 p. ct.	134.9= 8.23 p. ct.
III. Individuals omitted by Gephart and Du Bois	17	170.9=10.04 p. ct.	172.6=10.14 p. ct.	132.9= 7.81 p. ct.
IV. All individuals	64	139.2= 8.48 p. ct.	138.3= 8.43 p. ct.	125.6= 7.65 p. ct.
Equations based on 64 individuals not in Gephart and Du Bois selection:				
V. Gephart and Du Bois selection	72	110.2= 6.79 p. ct.	109.5= 6.75 p. ct.	110.2= 6.79 p. ct.
Women.				
Equations based on original series:				
VI. Supplementary series	35	173.5=12.96 p. ct.	171.8=12.84 p. ct.	169.1=12.63 p. ct.
Equations based on supplementary series:				
VII. Original series	68	120.2= 8.87 p. ct.	119.8= 8.84 p. ct.	120.4= 8.89 p. ct.

Possibly the results slightly favor the prediction of heat-production from the Du Bois height-weight chart, but the differences are by no means so large as would be implied by the statements of those who have urged that heat-production is proportional to body-surface but not to body-weight. Thus, in the instance among the larger series (IV–VII) most favorable to the body-surface theory, *i.e.*, that in which there is a square root of mean-square deviation of 7.65 per cent in predicting the metabolism of the individuals of an unmeasured series from body surface and of 8.48 per cent in predicting from body-weight, the error of prediction is only $8.48-7.65=0.83$ per cent greater when body-weight is used as a base. We shall return to these problems in a subsequent section.

Summarizing the results of these tests of body-surface as measured by the Du Bois height-weight chart in comparison with body-weight

as a basis of the prediction of the heat-production of a subject, we note the following points from the two major series of each sex (series IV–VII, tables 60–62, 66–68).

1. In testing the two bases of prediction, body-weight and body-surface, by the average deviation with regard to sign of the predicted from the actually observed values, we find that in predicting by the use of mean heat-production per unit of weight and of mean heat-production per unit of surface area, body-surface gives the lower average deviation in three of the four series (table 60). When prediction is made by means of the linear regression equations, body-surface gives the lower average deviation in all four series (table 66).

2. In testing the two bases of prediction by means of the average deviation without regard to sign of the predicted from the observed values, we find that in predicting from mean heat per unit of weight and from mean heat per unit of area, body-surface is the better basis of prediction in all four cases (IV–VII, table 61). In predicting by the use of equations we find that surface is the better basis of prediction in three of the four cases, but slightly worse than body-weight in series V, table 67.

3. In testing the two bases of prediction by the square root of mean-square deviation of the predicted from the observed values, we find that in predicting from mean heat-production per unit, body-surface gives lower deviations from the actually measured heat-productions than body-weight (table 62). In predicting by equations, body-surface gives the closer agreement of prediction with observation in two of the series (IV, VI), but the two methods are, practically speaking, equally good in the other two series (V, VII, table 68).

The net result of this analysis seems to be that metabolism can be predicted more accurately from body-surface than from body-weight. The difference between these two means of prediction *depends in a very large degree upon the method of calculation used*, and somewhat upon the criterion of accuracy of prediction adopted. *With the best methods of calculation the difference between the accuracy of prediction from body-weight and that from body-surface is not very large.*

8. FURTHER TESTS OF THE VALUE OF BODY-WEIGHT AND BODY-SURFACE FOR ESTIMATING TOTAL HEAT-PRODUCTION.

The practical importance of the solution of the problem of predicting the metabolism of the individual with the highest attainable degree of accuracy is so great that we shall apply one further test of the relative value of body-weight and body-surface area as measured by the Du Bois height-weight chart. In the preceding tests we have adhered strictly to the procedure which is theoretically the best and which fulfills exactly the conditions to be met in practice. That is, in the case of a subject whose metabolism is assumed to be unknown, we have

predicted the heat-production from constants based on other series of individuals taken as the bases of standard constants. The comparison of heat-productions thus calculated with those which have been actually determined furnishes a test of the accuracy of prediction by the several methods to be tested.

From the theoretical side it is evident that in testing the value of any method of predicting metabolism, the measurement of an individual subject should not be included in the series upon which the constant or equation used in predicting his own metabolism is based. In other words, the metabolism of an individual should not be predicted from itself. This error has in essence been made by earlier writers in tests of the validity of the body-surface law.

But while a single aberrant subject might have great weight in determining a standard constant based on a *small* group of individuals, the importance of any single metabolism measurement rapidly decreases as the number included in the group becomes larger. Thus in our series of males one individual has a weight of only 1/136 and in our series of females one individual has a weight of only 1/103 in determining the constant for the whole series. In predicting the metabolism of really, and not merely supposedly, unknown subjects in the hospital ward the clinician should naturally use the constants based on our 136 men, not on the 72 of the Gephart and Du Bois selection or the 64 others. The same is true of the 103 women as compared with the two subseries of 35 and 68 individuals.

Since prediction constants based on these series, the largest available up to the present time, will be used in the calculation of controls, it seems desirable to determine the error of prediction of the heat-productions of the individual subjects, considered unknown, from prediction constants based on the series as a whole. If we follow the old practice of estimating the metabolism of a subject by multiplying his body-weight by the average heat-production per kilogram of body-weight, or his body-surface by the average heat-production per square meter of body-surface, we employ the following average values per 24 hours:

For men, $N=136$:	
Mean calories per kilogram	25.697
Mean calories per square meter of body-surface by height-weight chart	925.471
For women, $N=103$:	
Mean calories per kilogram	24.457
Mean calories per square meter of body-surface by height-weight chart	850.010

If, on the other hand, we desire to use the method proposed in this paper of predicting heat-production by use of regression equations, we have the following:

For men:

$h=617.493+15.824\,w \qquad h=-254.546+1070.454\,a_D.$

For women:

$h=884.528+8.227\,w \qquad h=333.618+638.610\,a_D.$

The results of predicting the heat-production of the 136 individual men and of the 103 individual women by these four methods are shown in table 69. Here the deviations of the calculated heat-production in calories per day are shown in units of 75 calories per day range as indicated in the first column. The frequencies of deviations of given grade are shown for the four different methods of calculation and for the two sexes in the following eight columns. This table brings out various facts which are not shown by the other methods of comparison hitherto employed.

1. The deviations of the predicted from the actually observed heat-productions may be very great. Differences of 188 calories and over, either above or below the observed values, occur in many cases.

TABLE 69.—*Comparison of amounts and frequencies of error by different methods of prediction based on all men and women.*

Deviation of calculated from observed heat-production in calories per day.	Men.				Women.			
	By mean heat per kilogram.	By mean heat per meter.	By regression of heat on weight.	By regression of heat on surface.	By mean heat per kilogram.	By mean heat per meter.	By regression of heat on weight.	By regression of heat on surface.
+863 to +937	..	..	..	..	1	..	..	..
+788 to +862	..	..	..	..	..	..	..	..
+713 to +787	..	..	..	..	..	..	..	..
+638 to +712	..	..	..	..	..	..	..	..
+563 to +637	..	..	..	..	3	..	..	..
+488 to +562	1	..	..	..	2	..	..	..
+413 to +487	2	..	..	..	2	..	..	..
+338 to +412	2	..	..	..	3	..	..	..
+263 to +337	5	2	2	2	3	4	..	..
+188 to +262	7	5	9	5	7	4	7	7
+113 to +187	16	14	13	15	7	13	12	13
+ 38 to +112	20	34	24	36	12	20	22	21
− 37 to + 37	31	34	39	30	16	24	23	26
− 38 to −112	23	26	22	29	20	22	23	18
−113 to −187	14	11	19	9	15	8	8	10
−188 to −262	13	6	7	9	6	5	3	5
−263 to −337	1	3	..	1	6	3	5	3
−338 to −412	1	1	1	..	..	..	..	..

2. The distribution of the errors of estimation is not chaotic, but remarkably regular in all cases. The errors form monomodal *more or less* symmetrical distributions, *i.e.*, they are distributed around a maximum control frequency.

3. The errors of estimation in the case of prediction from average heat-production per kilogram of body-weight are obviously far greater in both men and women than those resulting from any other method. The errors by this method tail off in the positive direction with a number of errors beyond the 338–412 calories class in the women.

Obviously, prediction from mean calories heat-production per kilogram of body-weight gives bad results in both sexes, *and particularly*

bad results in the case of the women. From mere inspection of the frequency distributions of this series of errors it is impossible to discriminate between the value of the three other methods of prediction.

Having recourse to the three tests of accuracy of prediction used in the foregoing discussion we find the following results *from the ungrouped deviations.* The average deviations of the predicted from the actually observed values *with regard to sign* are the following:

	Men.	*Women.*	*Difference.*
Calculated from body-weight			
By means	+15.346	+32.243	+16.897
By equations	− 0.007	− 0.019	+ 0.012
Difference	+15.339	+32.224	
Calculated from body-surface			
By means	− 0.919	+ 2.816	+ 1.897
By equations	+ 0.015	+ 0.029	+ 0.014
Difference	+ 0.904	+ 2.787	

This comparison brings out with great clearness three important results.

1. The average error with regard to sign of prediction from average heat-production per unit is enormously greater than that in prediction by the use of regression equations. This is true whether body-surface or body-weight be used as a basis of prediction.

2. The errors in predictions from body-surface by use of the mean heat per unit of body-surface in the standard series is far lower than that resulting from prediction from body-weight.

3. The errors of prediction are in all cases larger in the calculations for women than the comparable values for men.

As far as it goes, therefore, this test indicates the superiority of body-surface over body-weight as a basis of prediction.

The superiority of the regression equations for purposes of prediction over the old method of considering heat-production directly proportional to body-weight or body-surface is the most striking, and doubtless the most valuable, feature of this table. The old method of estimation gives average errors of from 0.9 of a calorie to over 32 calories per day, depending on the sex and method of prediction used. The new method of prediction *does not in any case give an average error of as much as 0.03 calorie per day!*

Turning now to the average deviations without regard to sign of the predicted from the observed values we have the following results:

	Men.	*Women.*	*Difference.*
Calculated from body-weight			
By means	122.5	165.3	+42.8
By equations	97.6	98.0	+ 0.4
Difference	+ 24.9	+ 67.3	
Calculated from body-surface			
By means	93.7	99.7	+ 6.0
By equations	92.0	97.2	+ 5.2
Difference	+ 1.7	+ 2.5	

The constants in this table show:

1. That in all four comparisons prediction from means gives a higher error than prediction by use of equations.

2. That prediction from body-surface gives lower average deviations than prediction from body-weight. This is true whether prediction is made by considering the production proportional to body-weight or body-surface, or as given by a linear equation.

3. That by all methods the error of prediction is larger in the women than that due to comparable methods in the men.

In prediction from body-weight the disadvantage of the method of estimation from average heat per unit is particularly conspicuous. It gives an average error of 24.9 calories in men and 67.3 calories per 24 hours in women greater than prediction from equations based on body-weight. In the case of prediction from body-surface the difference between the error resulting from the use of means and the use of equations is not so great, but amounts to 1.7 calories in men and 2.5 calories in women.

Results secured by the use of equations are conspicuously more consistent than those reached by prediction from means of heat-production per unit of surface. For example, in the men the mean error of the prediction of heat-production from the mean heat-production per kilogram in the series as a whole is 28.8 calories per 24 hours greater than prediction from the mean heat-production per square meter of body-surface in the whole series. For the women the difference is 65.6 calories. But when equations are used the excess error of 28.8 calories in the men shrinks to 5.6 calories and the excess error of 65.6 calories in the women shrinks to 0.8 calorie. Again, in comparing the men and the women we note differences of 42.8 and 6.0 calories when prediction is made by considering heat-production proportional to body-weight or body-surface, but these differences are only 0.4 and 5.2 calories per day when prediction is made by equations.

Turn now to our third and final standard of comparison—the square root of mean-square error of prediction.

	Men.	*Women.*	*Difference.*
Calculation from body-weight			
By means	160.99	225.74	+64.75
By equations	123.88	123.03	− 0.85
Difference	+ 37.11	+102.71	
Calculation from body-surface			
By means	119.44	126.81	+ 7.37
By equations	117.21	122.86	+ 5.65
Difference	+ 2.23	+ 3.95	

The conclusions to be drawn from this table are in essential agreement with those drawn from the preceding tests. Prediction from body-surface gives a far lower error than prediction from body-weight when heat-production is considered directly proportional to weight

and surface, but the errors of prediction are much more nearly equal when equations connecting body-weight and body-surface on the one hand and daily heat-production on the other are used. Thus differences of 41.55 and 98.93 calories in the results of prediction of metabolism by the use of mean calories per kilogram and mean calories per square meter are reduced to 6.67 and 0.17 calories when equations are used; and differences of 64.75 and 7.37 calories in the deviation of predicted from the observed standards in men and women when mean heat per kilogram and per square meter are used as a basis of prediction reduce to 0.85 and 5.65 calories when equations are employed for prediction.

Finally, comparing body-weight and body-surface as bases of prediction when the more satisfactory equation method is used for prediction, one finds surprisingly little difference between them. For men body-weight gives a square root of mean-square deviation of 123.88 calories per day, while body-surface gives 117.21 calories or only 6.67 calories less. For women the difference is only $123.03-122.86=0.17$ calorie per 24 hours. The reader must note that these differences are based on an average metabolism of 1631.74 calories per 24 hours in men and 1349.19 calories in women. Thus the differences are less than 0.5 per cent of the total metabolism in each case.

On the basis of such differences, who is prepared to assert that metabolism is proportional to body-surface but not to body-weight?

9. PREDICTION OF HEAT-PRODUCTION FROM TWO PHYSICAL CHARACTERS.

We shall now approach the problem of the basis of comparison of the metabolism of various individuals along what we believe to be an entirely novel line of attack. In a preceding section we have emphasized the view that the true test of any method for the reduction of the metabolism of individuals of different size and shapes to comparable terms *is its capacity for predicting an unknown metabolism.* This we believe to be not merely a logically sound position, but the one upon which the results of the greatest practical importance can be based. Aside from the purely physiological problem of the value to be assigned to the basal metabolism coefficient for the human species, the precise determination of the metabolism of the normal individual underlies a wide range of practical medical, economic, and social problems.

Take one illustration merely. A typhoid or goitre subject is placed in the respiration chamber and basal metabolism is calculated from gaseous exchange. This is merely a technical matter. The theoretical question which must be solved before these observational data have any medical significance is: What value should be assigned to the metabolism of this individual on the basis of his measurable bodily characters *on the assumption that he is in normal health?* In short, we

are forced to use his *predicted* metabolism in health as a basis of comparison with his *measured* metabolism in disease, in order to reach any conclusion of value concerning the influence of disease on metabolism.[80]

We shall now consider the possibility of predicting the basal metabolism of an individual by the simultaneous use of two physical characters. Should the method of the use of two or more characters prove more advantageous than the use of a single character, the selection of the most suitable physical characters for use in the estimation of the normal metabolism of the individual will present a problem of some practical importance. At present, it is quite natural to take the two measurements which are most easily and generally made, namely stature and body-weight.

Let s = stature, w = weight, h = total heat-production. Then the prediction of h from both s and w will be carried out by the formula[81]

$$h=\bar{h}+\frac{r_{hw}-r_{hs}r_{sw}}{1-r_{sw}^2}\cdot\frac{\sigma_h}{\sigma_w}(w-\bar{w})+\frac{r_{sh}-r_{hw}r_{ws}}{1-r_{sw}^2}\cdot\frac{\sigma_h}{\sigma_s}(s-\bar{s})$$

or in terms more convenient for purposes of calculation

$$h=\bar{h}-\frac{r_{hw}-r_{hs}r_{ws}}{1-r_{ws}^2}\cdot\frac{\sigma_h}{\sigma_w}\bar{w}-\frac{r_{hs}-r_{hw}r_{ws}}{1-r_{ws}^2}\cdot\frac{\sigma_h}{\sigma_s}\bar{s}$$
$$+\frac{r_{hw}-r_{hs}r_{ws}}{1-r_{ws}^2}\cdot\frac{\sigma_h}{\sigma_w}w+\frac{r_{hs}-r_{hw}r_{ws}}{1-r_{ws}^2}\cdot\frac{\sigma_h}{\sigma_s}s$$

Or following another notation[82] we may determine the prediction equations as follows:

The individual partial regression slopes are given by

$${}_s\rho_{wh}={}_sr_{wh}\frac{{}_{sw}\sigma_h}{{}_{sh}\sigma_w}\qquad {}_w\rho_{sh}={}_wr_{sh}\frac{{}_{sw}\sigma_h}{{}_{wh}\sigma_s}$$

where the three standard deviations of the second order, ${}_{sw}\sigma_h$, ${}_{sh}\sigma_w$ ${}_{wh}\sigma_s$, are given by

$${}_{sw}\sigma_h=\sigma_h\sqrt{1-r_{sh}^2}\sqrt{1-{}_sr_{wh}^2}=\sigma_h\sqrt{1-r_{wh}^2}\sqrt{1-{}_wr_{sh}^2}$$
$${}_{wh}\sigma_s=\sigma_s\sqrt{1-r_{sw}^2}\sqrt{1-{}_wr_{sh}^2}=\sigma_s\sqrt{1-r_{sh}^2}\sqrt{1-{}_hr_{sw}^2}$$
$${}_{sh}\sigma_w=\sigma_w\sqrt{1-r_{ws}^2}\sqrt{1-{}_sr_{sh}^2}=\sigma_w\sqrt{1-r_{wh}^2}\sqrt{1-{}_hr_{ws}^2}$$

[80] The emphasis which has been laid upon the variation in metabolism from individual to individual throughout this volume should have convinced the reader that conclusions concerning the influence of any disease on metabolism can never be safely drawn from the determinations based on a single individual. It is only when a number of comparisons are made that conclusions may be safely drawn. This point will be further considered in Chapter VIII.

[81] In this volume no attempt is made to discuss in detail the statistical theory employed, or even to give full citations of the literature. Multiple prediction formulas are treated by Pearson, Phil. Trans. Ser. A, 1896, **187**, p. 253; *loc. cit.* 1898, **192**, p. 169. Yule, *An Introduction to the Theory of Statistics*, London, 1911, Chapter XII gives a general discussion of the subject with bibliography. Some of the formulas have been given in the form used by Goring in *The English Convict*, London, 1913.

[82] Yule, Introduction to the Theory of Statistics, 1911, p. 236.

Substituting constants, we have the following prediction equations based on our principal series.

For the Gephart and Du Bois selection, $N=72$. . . . . $h = 111.296+14.876\,w+3.300\,s$.
For the 64 men not included in Gephart and Du Bois selection,
$h = -603.317+12.488\,w+8.275\,s$.
For all men of both series, $N=136$ . . . . $h = -314.613+13.129\,w+6.388\,s$.
For the original women, $N=68$. . . . . $h = 664.012+10.441\,w+0.753\,s$.
For supplementary series of women, $N=35$ . . . . $h = 477.082+5.577\,w+3.237\,s$.
For all women, $N=103$. . . . . $h = 713.016+8.063\,w+1.116\,s$.

These equations have been used for purposes of prediction and the calculated heat-productions compared with the actually observed productions, just as was done in the preceding sections in prediction from standard average values or by means of a linear equation based on one bodily measure only.

Thus we have predicted the total heat-production of the 64 individuals not included in the series selected by Gephart and Du Bois from equations based on stature and body-weight in the Gephart and Du Bois selection. Conversely, to secure a more exhaustive test of the value of our prediction formulas, we have estimated the total heat-production of the 72 individuals constituting the Gephart and Du Bois selection from the data of the 64 other males. Similarly, the total heat-production of the 35 supplementary women has been predicted from equations involving the constants for stature and body-weight in the original feminine series, and the values for the individuals of the original series have been predicted from the data of the supplementary series of women. Details are given on pages 161–176, tables 60–68.

The reader will bear in mind the fact that these predictions and comparisons with actually observed constants have been made for the purpose of determining the most suitable method for estimating the metabolism of a subject. The division of our materials to make this test possible naturally increases somewhat the probable errors of the constants of the prediction formulas. After the most suitable method for the calculation of the metabolism of an unknown subject has been determined, the constants for actual use in the establishment of standard control or check values will be based upon all the data at our disposal. In examining the results of the prediction of the metabolism of series of individuals by means of equations involving both body-weight and stature, our object has been to ascertain whether this method gave sensibly better results than other methods of prediction hitherto employed.

Since it has been shown in a preceding chapter that the correlation between stature and metabolism is relatively small as compared with that between body-weight and metabolism, it will be unnecessary to compare the results of prediction by the use of equations involving both stature and body-weight with those based on stature only. A more valuable test of the possible superiority of prediction from both

stature and body-weight may be obtained by a comparison with the results of prediction from body-weight only.

Since it has appeared that the prediction from body-surface as estimated by the Du Bois height-weight chart gives more reliable results than prediction from body-surface as computed from the Meeh formula, it seems superfluous to make the comparisons of the prediction methods here under consideration with those involving body-surface as measured by this now antiquated formula.

In the following tables we shall, therefore, compare the errors of estimation found in predicting metabolism from multiple regression equations involving stature and body-weight with those found by considering it proportional to body-weight and to body-surface by the

TABLE 70.—*Comparison of average deviation (in calories, with regard to sign) from the actual caloric-output, of heat-production calculated on the one hand from multiple regression equations involving body-weight and stature and on the other from (a) the mean heat-production per unit of body-weight and of surface by the Du Bois height-weight chart and from (b) the regression of total heat on body-weight and on surface area by the Du Bois height-weight chart.*

Series.	Prediction from regression equations involving stature and weight. I.	Comparison with results obtained by other methods.*			
		Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.
I	+14.8=0.92 p. ct.	−10.2=0.64 p. ct.	−10.0=0.62 p. ct.	+ 3.0=0.18 p. ct.	+7.3=0.45 p. ct.
II	+10.0=0.61 p. ct.	+ 5.3=0.32 p. ct.	+ 3.9=0.24 p. ct.	− 28.3=1.73 p. ct.	−2.5=0.15 p. ct.
III	− 5.1=0.30 p. ct.	−36.0=2.12 p. ct.	−33.1=1.95 p. ct.	− 62.5=3.67 p. ct.	−4.6=0.27 p. ct.
IV	+ 8.1=0.50 p. ct.	+ 6.7=0.41 p. ct.	+ 5.6=0.35 p. ct.	− 26.4=1.60 p. ct.	−1.5=0.08 p. ct.
V	− 6.5=0.40 p. ct.	+ 3.0=0.18 p. ct.	+ 2.4=0.15 p. ct.	+ 3.5=0.22 p. ct.	−0.9=0.06 p. ct.
VI	+77.7=5.80 p. ct.	− 0.2=0.02 p. ct.	+ 4.5=0.33 p. ct.	−114.0=8.52 p. ct.	−0.2=0.02 p. ct.
VII	−49.8=3.68 p. ct.	−20.1=1.48 p. ct.	− 1.7=0.12 p. ct.	− 66.8=4.93 p. ct.	−3.5=0.25 p. ct.
Men	±00.0=0.00 p. ct.	− 0.9=0.06 p. ct.	± 0.0=0.00 p. ct.	− 15.4=0.94 p. ct.	±0.0=0.00 p. ct.
Women	±00.0=0.00 p. ct.	− 2.8=0.21 p. ct.	± 0.0=0.00 p. ct.	− 32.2=2.39 p. ct.	±0.0=0.00 p. ct.

* The differences in these columns are obtained from the first column of this table and the entries of preceding tables as follows: column II from III of table 60; column III from III of table 66; column IV from I of table 60; column V from I of table 66.

Du Bois height-weight chart, and when given by a linear-regression equation in which heat is predicted from body-weight or from body-surface by the height-weight chart.

Table 70 gives the average deviations with regard to sign of the theoretical heat-productions calculated by the multiple-prediction equation from the observed values and compares these deviations with those computed by the four other methods. Comparing the average deviations with regard to sign of the constants computed by the various methods in table 70, we note that in 2 of the 4 larger series (IV–VII), in which the prediction of the metabolism of the individuals of one series is made from the equations based on another series of individuals of the same sex, prediction by the simultaneous use of stature and

body-weight gives a slightly larger average error than prediction from body-surface by the Du Bois height-weight chart when prediction from body-surface is made by considering that the heat-production of an individual is given by

$$h = a_D \bar{h}_D$$

where a_D is the superficial area of the individual by the Du Bois height-weight chart and $\bar{h}_D$ the average heat-production per square meter in the standard population. In two cases, VI and VII, it gives a smaller average deviation from the ideal zero error.

When the best measure of heat-production on the basis of a single physical measurement is supposed to be given by

$$h = \left(\bar{h} - r \frac{\sigma_h}{\sigma_{a_D}} \bar{a}_D \right) + r \frac{\sigma_h}{\sigma_{a_D}} a_D$$

as we have demonstrated to be the case, the multiple regression equation gives slightly higher error in three of the four larger series.

The difference between the results of predicting heat-production by the use of multiple regression equations involving stature and weight and those due to the use of linear equations for prediction from body-surface by the Du Bois height-weight chart is, however, very slight indeed. In only 1 of the 8 comparisons is the difference over 7 calories. The difference in the percentage value of the average deviations with regard to sign of the two methods of prediction is in only 1 case over 0.5 per cent in the 8 comparisons based on larger series.

When the values of the individual subjects are computed from equations based on the entire material for each sex (136 men and 103 women, as given in the two lower rows of the table) the average deviation with regard to sign is theoretically 0, and for all practical purposes empirically 0 in our actual observational data. *As far as this criterion can show*, all three regression methods seem equally good when predictions of individual values are made from the constants of the population to which they belong. Therefore, either of these three methods necessarily gives better results *as measured by this criterion* than either of the two methods of calculation from average heat-production per unit of weight or per unit of body-surface area in the standard series.

Turning now to the average deviations without regard to sign, as shown in table 71, we note practically the same relationship between the results for the 3 sets of formulas as in the preceding comparisons. Confining our attention to the 4 larger groups (IV–VII), in which prediction is made from the constants of another series of individuals, we note that in 5 of the 8 comparisons the multiple prediction equation shows (as indicated by the positive sign) a slightly larger, but only slightly larger, error than prediction from body-surface. The difference is in no case as much as 4.5 calories. In percentages of the average

measured heat-productions for the group under consideration, the differences in the errors of prediction range from 0.00 per cent to 0.29 per cent.

If the test be based upon the whole series of men and of women we find that the multiple regression equations give better results in every case but one. In this case prediction from the linear equation for total heat on body-surface area gives a mean deviation 0.2 calorie per day less in the men than the multiple regression equations. This represents a difference of 0.01 per cent only.

The comparison on the basis of square root of mean-square deviation is made in table 72. The results show that in 6 of the 8 larger series (IV–VII) in which prediction is made from constants based upon

Table 71.—*Comparison of average deviation (in calories, without regard to sign) from the actual caloric-output, of heat production calculated on the one hand from multiple regression equations involving body-weight and stature and on the other from (a) the mean heat-production per unit of body weight and of surface by the Du Bois height-weight chart and from (b) the regression of total heat on body-weight and on surface area by the Du Bois height-weight chart.*

Series.	Prediction from regression equations involving stature and weight. I.	Comparison with results obtained by other methods.*			
		Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.
I..........	87.9= 5.48 p. ct.	− 6.2=0.38 p. ct.	− 1.7=0.10 p. ct.	− 4.9=0.30 p. ct.	− 3.2=0.19 p. ct.
II.........	99.1= 6.04 p. ct.	− 0.6=0.04 p. ct.	− 1.7=0.11 p. ct.	− 27.9=1.71 p. ct.	− 0.3=0.02 p. ct.
III........	127.2= 7.48 p. ct.	+17.8=1.05 p. ct.	+20.8=1.23 p. ct.	−107.4=6.31 p. ct.	−21.9=1.28 p. ct.
IV........	101.7= 6.20 p. ct.	+ 1.9=0.12 p. ct.	+ 4.3=0.27 p. ct.	− 38.9=2.37 p. ct.	− 7.3=0.44 p. ct.
V.........	88.6= 5.46 p. ct.	− 0.1=0.00 p. ct.	− 0.1=0.00 p. ct.	− 17.8=1.09 p. ct.	+ 0.5=0.03 p. ct.
VI........	150.0=11.21 p. ct.	+ 0.1=0.01 p. ct.	+ 3.9=0.29 p. ct.	− 93.7=7.00 p. ct.	± 0.0=0.00 p. ct.
VII.......	94.0= 6.94 p. ct.	− 0.6=0.04 p. ct.	+ 0.9=0.07 p. ct.	− 75.8=5.59 p. ct.	− 2.1=0.15 p. ct.
Men.......	92.2= 5.65 p. ct.	− 1.5=0.10 p. ct.	+ 0.2=0.01 p. ct.	− 30.3=1.86 p. ct.	− 5.3=0.33 p. ct.
Women....	93.6= 6.94 p. ct.	− 6.1=0.45 p. ct.	− 3.6=0.26 p. ct.	− 71.7=5.31 p. ct.	− 4.4=0.32 p. ct.

* The differences in these columns are obtained from the first column of this table and the entries of preceding tables as follows: column II from III of table 61; column III from III of table 67; column IV from I of table 61; column V from I of table 67.

a different group the error of prediction is greater by the equations here being tested than by prediction from body-surface by the Du Bois height-weight chart. The difference between the two methods is, however, very slight. In working units, it ranges from 1.1 to 4.7 calories per day. In terms of percentages of the average daily heat-production of the series of individuals dealt with, the differences in the errors of estimation by the multiple-regression equations and the prediction method based on body-surface range from 0.04 to 0.33 per cent.

Turning to a comparison of the various methods of calculation when the whole series of men and women are used, it appears in every case except one that the multiple regression equations give the more accurate prediction of metabolism.

Now, if we return to the differences in these three tables and consider together the three criteria of excellence of prediction—each of which has some advantages but neither of which is perfect—as a basis for a generalization concerning the value of the two methods under consideration, we note the following points:

1. The results in the first difference column show that prediction from the two direct measurements *stature* and *body-weight* gives more accurate results than the method of calculation from body-surface area by the Du Bois height-weight chart heretofore employed.

2. The second difference column suggests that *when the more accurate method of prediction by means of linear regression equations suggested in this volume is substituted for the old method* slightly more accurate predictions may be made from body-surface area than from multiple regression equations involving height and weight.

TABLE 72.—*Comparison of square root of mean-square deviation (in calories) from the actual caloric-output, of heat-production, calculated on the one hand from multiple regression equations involving body-weight and stature and on the other from (a) the mean heat-production per unit of body-weight and of surface by the Du Bois height-weight chart and from (b) the regression of total heat on body-weight and on surface area by the Du Bois height-weight chart.*

Series.	Prediction from regression equations involving stature and weight. I.	Comparison with results obtained by other methods.*			
		Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.
I........	110.7 = 6.90 p. ct.	−6.6 = 0.41 p. ct.	− 3.2 = 0.20 p. ct.	− 25.5 = 1.59 p. ct.	− 1.1 = 0.07 p. ct.
II........	139.4 = 8.50 p. ct.	+5.0 = 0.30 p. ct.	+ 4.5 = 0.27 p. ct.	− 31.9 = 1.95 p. ct.	− 4.4 = 0.27 p. ct.
III.......	148.6 = 8.73 p. ct.	+9.5 = 0.55 p. ct.	+15.7 = 0.92 p. ct.	−119.5 = 7.03 p. ct.	−22.3 = 1.31 p. ct.
IV.......	130.3 = 7.94 p. ct.	+1.8 = 0.11 p. ct.	+ 4.7 = 0.29 p. ct.	− 59.2 = 3.61 p. ct.	− 8.9 = 0.54 p. ct.
V........	111.3 = 6.86 p. ct.	+0.7 = 0.05 p. ct.	+ 1.1 = 0.07 p. ct.	− 20.9 = 1.29 p. ct.	+ 1.1 = 0.07 p. ct.
VI.......	173.5 = 12.96 p. ct.	−0.5 = 0.04 p. ct.	+ 4.4 = 0.33 p. ct.	−154.3 = 11.53 p. ct.	± 0.0 = 0.00 p. ct.
VII......	121.0 = 8.93 p. ct.	−1.1 = 0.08 p. ct.	+ 0.6 = 0.04 p. ct.	− 80.1 = 5.92 p. ct.	+ 0.8 = 0.06 p. ct.
Men......	117.4 = 7.19 p. ct.	−2.0 = 0.13 p. ct.	+ 0.2 = 0.01 p. ct.	− 43.6 = 2.68 p. ct.	− 6.5 = 0.40 p. ct.
Women...	117.4 = 8.70 p. ct.	−9.5 = 0.70 p. ct.	− 5.5 = 0.41 p. ct.	−108.4 = 8.03 p. ct.	− 5.7 = 0.42 p. ct.

* The differences in these columns are obtained from the first column of this table and the entries of the preceding tables as follows: column II from III of table 62; column III from III of table 68; column IV from I of table 62; column V from I of table 68.

3. The third difference column shows that practically without exception (25 out of 27 tests) better prediction can be made from multiple regression equations than by considering heat-production in the individual as given by (body-weight × mean heat-production per kilogram in the control series).

4. Even when the superior method of predicting from the regression of heat-production on body-weight introduced in this paper is employed instead of the older method, the multiple regression equation in which prediction is based on both stature and body-weight gives far better results (as shown by the preponderance of negative signs in the final difference column) than prediction from weight alone.

10. PREDICTION OF HEAT-PRODUCTION FROM TWO PHYSICAL CHARACTERS (STATURE AND BODY-WEIGHT) AND AGE.

In the foregoing section we demonstrated the efficiency of equations involving stature and body-weight for the prediction of the heat-production of the individual. From the analyses in the preceding chapter it is clear that age is another factor which should be taken into account in estimating the basal metabolism of the individual.

Our problem in this section is therefore twofold: First, we must determine some means of including an age factor in our prediction equation. Second, we must, on the basis of the available observational data, replace the symbols in these equations by numerical constants and determine empirically whether equations involving age as well as body-weight and stature show a superiority for the prediction of the heat-production of the unknown subject. While Du Bois has given a tentative correction for age we have not considered it worth while, in view of the very approximate nature of his terms as given on page 123 to apply his age correction in drawing a comparison between equations based on body-surface and those based on stature, weight, and age.

Working in terms of partial correlations and variabilities, the multiple-prediction formulas for the estimation of total heat-production from stature, body-weight, and age require:

Partial correlation between weight and total heat-production for constant stature and age, ${}_{sa}r_{wh}$.

Partial correlation between stature and total heat-production for constant weight and age, ${}_{wa}r_{sh}$.

Partial correlation between age and total heat-production for constant weight and stature, ${}_{ws}r_{ah}$.

Partial correlation between age and stature for constant body-weight and daily heat-production, ${}_{hw}r_{as}$.

Partial correlation between stature and weight for constant age and daily heat-production, ${}_{ah}r_{sw}$.

These are:

$$ {}_{sa}r_{wh} = \frac{r_{wh}(1-r_{as}^2)-r_{aw}r_{ah}-r_{sw}r_{sh}+r_{as}(r_{aw}r_{sh}+r_{ah}r_{sw})}{\sqrt{(1-r_{as}^2-r_{sw}^2-r_{aw}^2+2r_{as}r_{aw}r_{sw})}\sqrt{(1-r_{as}^2-r_{sh}^2-r_{ah}^2+2r_{as}r_{ah}r_{sh})}} $$

$$ {}_{wa}r_{sh} = \frac{r_{sh}(1-r_{aw}^2)-r_{as}r_{ah}-r_{ws}r_{wh}+r_{aw}(r_{as}r_{wh}+r_{ah}r_{ws})}{\sqrt{(1-r_{aw}^2-r_{ws}^2-r_{as}^2+2r_{aw}r_{as}r_{ws})}\sqrt{(1-r_{aw}^2-r_{wh}^2-r_{ah}^2+2r_{aw}r_{ah}r_{wh})}} $$

$$ {}_{ws}r_{ah} = \frac{r_{ah}(1-r_{sw}^2)-r_{sa}r_{sh}-r_{wa}r_{wh}+r_{sw}(r_{sa}r_{wh}+r_{sh}r_{wa})}{\sqrt{(1-r_{sw}^2-r_{wa}^2-r_{sa}^2+2r_{sw}r_{sa}r_{wa})}\sqrt{(1-r_{sw}^2-r_{wh}^2-r_{sh}^2+2r_{sw}r_{sh}r_{wh})}} $$

$$ {}_{hw}r_{as} = \frac{r_{sa}(1-r_{hw}^2)-r_{hs}r_{ha}-r_{ws}r_{wa}+r_{hw}(r_{hs}r_{wa}+r_{ha}r_{ws})}{\sqrt{(1-r_{hw}^2-r_{ws}^2-r_{hs}^2+2r_{hw}r_{hs}r_{ws})}\sqrt{(1-r_{hw}^2-r_{wa}^2-r_{ha}^2+2r_{hw}r_{ha}r_{wa})}} $$

$$ {}_{ah}r_{sw} = \frac{r_{sw}(1-r_{ah}^2)-r_{as}r_{aw}-r_{hs}r_{hw}+r_{ah}(r_{as}r_{hw}+r_{aw}r_{hs})}{\sqrt{(1-r_{ah}^2-r_{hs}^2-r_{as}^2+2r_{ah}r_{as}r_{hs})}\sqrt{(1-r_{ah}^2-r_{hw}^2-r_{aw}^2+2r_{ah}r_{aw}r_{hw})}} $$

The first three lead to the partial regressions which are required for computing the variations in heat-productions associated with differences in weight, stature, and age. The last two are useful in checking the partial variabilities. The partial regressions are:

$$_{sa}\rho_{wh} = {}_{sa}r_{wh}\frac{_{wsa}\sigma_h}{_{sah}\sigma_w} \qquad _{wa}\rho_{sh} = {}_{wa}r_{sh}\frac{_{wsa}\sigma_h}{_{wah}\sigma_s} \qquad _{ws}\rho_{ah} = {}_{ws}r_{ah}\frac{_{wsa}\sigma_h}{_{wsh}\sigma_a}$$

where the partial variabilities are given by

$$\begin{aligned}
_{wsa}\sigma_h &= \sigma_h\sqrt{1-r_{wh}^2}\sqrt{1-{}_{w}r_{sh}^2}\sqrt{1-{}_{ws}r_{ah}^2} \\
&= \sigma_h\sqrt{1-r_{ah}^2}\sqrt{1-{}_{a}r_{sh}^2}\sqrt{1-{}_{sa}r_{wh}^2} \\
_{sah}\sigma_w &= \sigma_w\sqrt{1-r_{ws}^2}\sqrt{1-{}_{s}r_{wa}^2}\sqrt{1-{}_{sa}r_{wh}^2} \\
&= \sigma_w\sqrt{1-r_{wh}^2}\sqrt{1-{}_{h}r_{wa}^2}\sqrt{1-{}_{ah}r_{ws}^2} \\
_{wah}\sigma_s &= \sigma_s\sqrt{1-r_{sa}^2}\sqrt{1-{}_{a}r_{sh}^2}\sqrt{1-{}_{ah}r_{sw}^2} \\
&= \sigma_s\sqrt{1-r_{sw}^2}\sqrt{1-{}_{w}r_{sh}^2}\sqrt{1-{}_{hw}r_{sa}^2} \\
_{wsh}\sigma_a &= \sigma_a\sqrt{1-r_{ah}^2}\sqrt{1-{}_{h}r_{aw}^2}\sqrt{1-{}_{hw}r_{as}^2} \\
&= \sigma_a\sqrt{1-r_{as}^2}\sqrt{1-{}_{s}r_{aw}^2}\sqrt{1-{}_{ws}r_{ah}^2}
\end{aligned}$$

These give the characteristic equation

$$h = (\bar{h} - {}_{sa}\rho_{wh}\bar{w} - {}_{wa}\rho_{sh}\bar{s} - {}_{ws}\rho_{ah}\bar{a}) + {}_{sa}\rho_{wh}w + {}_{wa}\rho_{sh}s + {}_{ws}\rho_{ah}a$$

Substituting constants and having h = total heat-production per 24 hours, w = weight in kilograms, s = stature in centimeters, and a = age in years, we have for the six series of adults dealt with:

Gephart and Du Bois selection, $N=72$,	$h = +175.4866 + 13.0642\,w + 4.9520\,s - 9.1252\,a$
Men other than Gephart and Du Bois selection, $N=64$,	$h = -\ 67.3458 + 13.6734\,w + 5.7310\,s - 6.1234\,a$
Grand total men, $N=136$,	$h = +\ 66.4730 + 13.7516\,w + 5.0033\,s - 6.7550\,a$
Original women, $N=68$,	$h = +657.4595 + 10.3698\,w + 1.3988\,s - 3.5332\,a$
Supplementary women, $N=35$,	$h = +491.3238 + 8.4793\,w + 3.2667\,s - 4.8748\,a$
All women, $N=103$,	$h = +655.0955 + 9.5634\,w + 1.8496\,s - 4.6756\,a$

The testing of these formulas is carried out in precisely the same manner as that employed in dealing with those in which total heat-production was predicted from body-weight and stature in the preceding section. Thus tables 73 to 75 are quite comparable with tables 70 to 72. The first column gives the results of predictions of total heat-production from weight, stature, and age. The five following columns show the differences between these results and those obtained by other methods. The final column shows the difference between prediction from weight and stature as given in the first column of tables 70 to 72 and that from weight, stature, and age as given in the first column of tables 73 to 75. The subtractions are so made that a minus sign denotes a smaller error of prediction when the equation involving weight, stature, and age is used. In taking these differences in the case of

the average deviation of the calculated total heat-production with regard to signs, the signs of the constants in the first column of table 70 and in the first column of table 73 are disregarded, and the differences represent merely the difference in the numerical magnitudes of the discrepancy between observation and prediction.

Considering the values in table 73, we see that in some cases the equations involving weight, stature, and age give closer and in some cases slightly wider average deviations above or below the true value. In the larger series (IV–VII and total men and women) the equations

TABLE 73.—*Comparison of average deviation (in calories, with regard to sign) from actual, caloric-output of heat-production calculated on the one hand from multiple regression equations involving stature, body-weight, and age and on the other from (a) the mean heat-production per unit of body-weight and body-surface by Du Bois height-weight chart, from (b) the regression of total heat on body-weight and on body-surface by the Du Bois height-weight chart, and from (c) the regression of total heat-production on stature and body-weight.*

Series.	Prediction from regression equations involving stature, weight, and age. I.	Comparisons with results obtained by other methods.* Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.	Difference from prediction from regression equation for total heat on stature and weight. VI.
	cal. p ct.	*cal. p.ct.*	*cal. p.ct.*	*cal. p.ct.*	*cal. p.ct.*	*cal. p.ct.*
I......	+20.0=1.25	− 5.0=0.31	− 4.8=0.30	+ 8.2= 0.51	+12.5=0.78	+ 5.2=0.32
II.....	−51.0=3.11	+46.3=2.82	+44.9=2.74	+ 12.7= 0.77	+38.5=2.35	+41.0=2.50
III....	−36.8=2.16	− 4.3=0.25	− 1.4=0.08	− 30.8= 1.81	+27.1=1.59	+31.7=1.86
IV.....	−16.2=0.99	+14.8=0.90	+13.7=0.83	− 18.3= 1.11	+ 6.6=0.40	+ 8.1=0.49
V......	+ 7.6=0.47	+ 4.1=0.25	+ 3.5=0.22	+ 4.6= 0.28	+ 0.2=0.01	+ 1.1=0.07
VI.....	+30.8=2.30	−47.1=3.52	−42.4=3.17	−160.9=12.02	−47.1=3.52	−46.9=3.50
VII....	− 2.7=0.20	−67.2=4.96	−48.8=3.60	−113.9= 8.41	−50.6=3.74	−47.1=3.48
Men...	± 0.0=0.00	− 0.9=0.05	± 0.0=0.00	− 15.3= 0.94	± 0.0=0.00	±00.0=0.00
Women	± 0.0=0.00	− 2.8=0.21	± 0.0=0.00	− 32.2= 2.39	± 0.0=0.00	±00.0=0.00

* The differences in these columns are obtained from the first column of this table and the entries of preceding tables as follows: column II from III of table 60; column III from III of table 66; column IV from I of table 60; column V from I of table 66; column VI from I of table 70.

which take into account weight, stature, and age give somewhat better results than those in which prediction is made by the other methods employed.

The figures set forth in tables 74 and 75 are so striking that they require but few words of discussion. Consider table 74 showing the average deviations without regard to sign of the calculated from the actually determined heat-productions in the several series of individuals when the former are computed in various ways. With one single and numerically insignificant (+0.7 =0.04 per cent) exception the 45 differences are negative in sign, showing that the error of prediction is smaller when multiple regression equations involving weight, stature, and age are used than when any of the other 5 methods of estimating the heat-production of a subject is employed. In the larger series (IV–VII and

TABLE 74.—*Comparison of average deviation (in calories, without regard to sign) from the actual coloric-output, of heat-production calculated on the one hand from multiple regression equations involving body-weight, stature, and age and on the other from (a) the mean heat-production per unit of body-weight and of surface by the Du Bois height-weight chart, from (b) the regression of total heat on body-weight and on body-surface, and from (c) the regression of total heat-production on stature and body-weight.*

Series.	Prediction from regression equations involving stature, weight, and age. I.	Comparisons with results obtained by other methods.* Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.	Difference from prediction from regression equation for total heat on stature and weight. VI.
	cal. *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*
I......	88.6=5.52	− 5.5=0.34	− 1.0=0.06	− 4.2= 0.26	− 2.5=0.16	+ 0.7=0.04
II.....	98.8=6.02	− 0.9=0.05	− 2.0=0.12	− 28.2= 1.72	− 0.6=0.04	− 0.3=0.02
III....	86.8=5.10	−22.6=1.33	−19.6=1.15	−147.8= 8.69	−62.3=3.66	−40.4=2.37
IV.....	91.1=5.55	− 8.7=0.53	− 6.3=0.38	− 49.5= 3.02	−17.9=1.09	−10.6=0.65
V......	79.1=4.87	− 9.6=0.59	− 9.6=0.59	− 27.3= 1.68	− 9.0=0.55	− 9.5=0.59
VI.....	109.7=8.20	−40.2=3.00	−36.4=2.72	−134.0=10.01	−40.3=3.01	−40.3=3.01
VII....	75.8=5.60	−18.8=1.39	−17.3=1.28	− 94.0= 6.93	−20.3=1.50	−18.2=1.34
Men...	81.2=4.98	−12.5=0.77	−10.8=0.66	− 41.3= 2.53	−16.4=1.01	−11.0=0.67
Women	84.6=6.27	−15.1=1.12	−12.6=0.93	− 80.7= 5.98	−13.4=0.99	− 9.0=0.67

* The differences in these columns are obtained from the first column of this table and the entries of the preceding tables as follows: column II from III of table 61; column III from III of table 67; column IV from I of table 61; column V from I of table 67; column VI from I of table 71.

TABLE 75.—*Comparison of square root of mean-square deviation (in calories) from the actual caloric-output of heat-production calculated on the one hand from multiple regression equations involving body-weight, stature, and age, and on the other from (a) the mean heat-production per unit of body-weight and of surface by the Du Bois height-weight chart, from (b) the regression of total heat on body-weight and on body-surface by the Du Bois height-weight chart and from (c) the regression of total heat on stature and body-weight.*

Series.	Prediction from regression equations involving stature, weight, and age. I.	Comparisons with results obtained by other methods.* Difference from prediction from average heat per square meter of body-surface. II.	Difference from prediction from regression equation for total heat on body-surface. III.	Difference from prediction from average heat per kilogram of body-weight. IV.	Difference from prediction from regression equation for total heat on body-weight. V.	Difference from prediction from regression equation for total heat on stature and weight. VI.
	cal. *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*	*cal.* *p.ct.*
I......	104.3= 6.50	−13.0=0.81	− 9.6=0.60	− 31.9= 1.99	− 7.5=0.47	− 6.4=0.40
II.....	137.5= 8.38	+ 3.1=0.19	+ 2.6=0.16	− 33.8= 2.06	− 6.3=0.38	− 1.9=0.12
III....	94.4= 5.55	−44.7=2.63	−38.5=2.26	−173.7=10.21	−76.5=4.50	−54.2=3.19
IV.....	112.9= 6.88	−15.6=0.95	−12.7=0.77	− 76.6= 4.67	−26.3=1.60	−17.4=1.06
V......	98.3= 6.05	−12.3=0.76	−11.9=0.73	− 33.9= 2.09	−11.9=0.73	−13.0=0.80
VI.....	136.4=10.19	−37.6=2.81	−32.7=2.44	−191.4=14.30	−37.1=2.77	−37.1=2.77
VII....	94.2= 6.95	−27.9=2.06	−26.2=1.93	−106.9= 7.89	−26.0=1.92	−26.8=1.98
Men...	101.7= 6.23	−17.7=1.08	−15.5=0.95	− 59.3= 3.63	−22.2=1.36	−15.7=0.96
Women	106.3= 7.88	−20.5=1.52	−16.6=1.23	−119.4= 8.85	−16.7=1.24	−11.1=0.82

* The differences in these columns are obtained from the first column of this table and the entries of preceding tables as follows: column II from III of table 62; column III from III of table 68; column IV from I of table 62; column V from I of table 68; column VI from I of table 72.

totals) the differences range from 6.3 to 134.0 calories, or from 0.38 to 10.01 per cent of the average (24-hour) heat-production of the group of subjects under consideration.

If one prefers to base his judgment concerning the value of the different means of estimating the basal metabolism of an unknown subject upon the square root of the mean-square deviation of the computed from the actually observed values, he may examine the results set forth in table 75. Here again the 45 tests of the suitability of the multiple regression equation involving stature, weight, and age with two trivial exceptions (+2.6 calories = 0.16 per cent and +3.1 calories = 0.19 per cent) indicate the superiority of these equations over the 5 other methods which have been tested. The values for the larger series (IV–VII and totals) range from 0.73 to 14.30 per cent.

Considered in their relation to the problem of the present chapter, that of the body-surface law, the tables of this and the preceding section show that *results as good as or better than those obtainable from the constant of basal metabolism per square meter of body-surface can be obtained by biometric formulas involving no assumption concerning the derivation of surface-area but based on direct physical measurements.*

To the practical application of these formulas we shall return in the two following chapters.

11. COMPARISON OF BODY-WEIGHT AND BODY-SURFACE AS BASES OF PREDICTION IN MALE AND FEMALE INFANTS.

Unfortunately our series of new-born infants are not large enough to justify division into subseries for the purpose of testing the suitability of different methods of prediction by the treatment of the individuals of one subseries as unknown. We must, therefore, test the value of the different methods of predicting the total heat-production of an infant by comparing the actually measured heat-production with that computed from constants based on the series to which it belongs.[83]

It seems worth while to test only the methods of predicting total heat-production from body-weight and from body-surface by the linear regression equations, and by multiple-regression equations based on both weight and stature.

The linear equations required are:

For male babies:	For female babies:
$h = 25.156 + 34.517\,w$	$h = 26.184 + 34.229\,w$
$h = -31.703 + 749.914\,a_L$	$h = -32.048 + 751.548\,a_L$

[83] Unfortunately the Du Boises have not as yet prepared a height-weight chart for infants and we are in consequence limited to the Lissauer formula, which may in time be discarded like the Meeh formula for adults. An extensive series of measurements made in conjunction with Dr. Fritz B. Talbot and according to the Du Bois plan of measurement has shown quite remarkable agreement between the surface areas of infants computed (1) by the Lissauer formula (2) by the Du Bois linear formula, *i. e.*, so far as normal infants weighing up to approximately 10 kilograms are concerned. For infants weighing more than 10 kilograms the Lissauer formula gives results unquestionably too small. Measurements are now being collected for undernourished and atrophic infants.

In male and female infants the deviations of the heat predicted by use of these equations from the actually measured heat-productions are:

	Boy babies.	Girl babies
Average deviations with regard to sign:		
Prediction from weight	−0.020	−0.093
Prediction from surface	+0.118	+0.047
Average deviations without regard to sign:		
Prediction from weight	11.04	11.16
Prediction from surface	11.10	11.02
Square root of mean-square deviations:		
Prediction from weight	13.81	13.77
Prediction from surface	13.80	13.61

These results show how slender is the evidence furnished by infants for the assertion that "heat-production is proportional to body-surface and not proportional to body-weight." By the first criterion, surface-area is slightly *better* in the females but slightly *worse* in the males. The average deviations without regard to sign show that in the females prediction from body-surface there is an average error of 0.14 *calorie per day* less than in prediction from body-weight, but that in the males prediction from body-surface area by the Lissauer formula gives 0.06 calorie worse prediction! Relying upon the square root of mean-square deviation for the most critical test, we note that there is a difference between the two methods of only 0.01 and 0.16 *calorie per day!* The differences are trivial in comparison with the average daily metabolism of over 140 calories for infants of both sexes. In short, body-weight and body-surface area are equally good for purposes of prediction.

Turning now to the prediction of total heat-production from multiple regression equations based on the whole series, we have the equations,

For boy babies............ $h = -22.104 + 31.050\,w + 1.162\,s$
For girl babies............ $h = -44.901 + 27.836\,w + 1.842\,s$

The theoretical heat-production for each infant has been calculated by these formulas and compared with the actually observed heat-production.

The theoretical average deviation with regard to sign is zero and is actually −0.078 calorie per day in the males and −0.047 calorie per day in the females. The average deviation without regard to sign is 11.02 calories in the males and 10.84 calories per 24 hours in the females. Measuring the suitability of the formulas by the square root of mean-square deviations we find 13.78 calories for the males and 13.53 calories for the females.

Comparing these results with those secured by prediction from body-weight and body-surface above, we note that prediction from stature and body-weight simultaneously has given *slightly better results than prediction from either body-weight or body-surface alone.*

12. RECAPITULATION AND DISCUSSION.

According to Rubner's "law" or the body-surface "law" the heat-production of an organism is proportional to its superficial area. Otherwise stated, heat-production measured in calories per square meter of body-surface is a constant.

In this chapter we have outlined the historical development of the physiologist's belief in the validity of this "law," have discussed certain experimental evidences for its inapplicability to man, and have tested its validity by the application of statistical criteria to the largest available series of data on human basal metabolism.

Historically, the idea of proportionality between body-surface and heat-production was originally based upon the assumed physical law, confused by many physiologists with Newton's law of cooling, that heat-loss is proportional to the surface-areas of similar solids, and upon the further assumption that heat is produced to maintain the body-temperature constant. The idea of a causal relationship between body-surface and heat-production has frequently been strongly emphasized in foreign writings and is distinctly to be inferred from those of a number of American writers.

The validity of the body-surface law has long been held in question by the workers at the Nutrition Laboratory. In a series of papers [84] its universal applicability was challenged and it was stated that the loss of heat from the body-surface could not be considered as the determining factor of metabolism. Certain factors, such as sex, age, and athletic training, were shown to affect the basal metabolism, even when measured on the basis of calories per square meter of body-surface, thus affording illustrations of exceptions to the so-called law.

In dealing with the problem of the constancy of heat-production per square meter of body-surface in the human species two phases must be recognized. The first is that of the constancy of heat-production within the same individual at different times. The second is that of the constancy of heat-production per square meter of body-surface from individual to individual.

From the side of controlled individual experimentation it has been shown that animals at different nutritional levels, or under varying external conditions, differ in their heat loss to a degree which can not be explained by differences in body-surface.

A man who fasted 31 days showed a decrease of 28 per cent in heat-production per square meter of body-surface. Squads of college men recently investigated on prolonged reduced diet at the International Y. M. C. A. College at Springfield gave ample corroborative evidence. Such experiments can be interpreted only as proof of the inapplicability

[84] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139; Benedict and Roth, *ibid*, 1915, **20**, p. 231; Benedict and Smith, *ibid.*, 1915, **20**, p. 243; Benedict and Emmes, *ibid.*, 1915, **20**, p. 253; Benedict, *ibid.*, 1915, **20**, p. 263.

of the surface-area law to subjects in widely varying states of nutrition. Criticism will of course be at once directed against the use of such evidence. It will be contended that prerequisite conditions for the application of the surface law as outlined by Rubner [85] are like physiological conditions, such as nourishment, climatic influences, temperature, and capacity for work. Just such adverse criticism has been made of conclusions drawn at the Nutrition Laboratory concerning the basal metabolism of normal and atrophic infants.

In reply to such comment it is necessary to point out merely that the physiological states of the fasting man are by no means incomparable with the conditions commonly existing in pathological subjects. Notwithstanding the fact that enormous variations in the previously mentioned physiological factors are invariably found, their metabolism has been treated by authors just as though the body-surface law were fully applicable. For example, in a report on a series of observations made in the Nutrition Laboratory on patients with severe diabetes [86] the metabolism of the diabetics was compared with that found in normal individuals of like height and weight, *i.e.*, of a somewhat thin and emaciated type. The marked difference in metabolism found with diabetics when acidosis was present as compared with that when it was diminished or absent [87] led to the conclusion that diabetes increases the metabolism approximately 15 to 20 per cent above that of the normal individual. When a wholly arbitrary normal standard value (obtained with a large number of individuals of whom the greater proportion were in full vigor) was used for comparison, Graham Lusk concluded [88] that the emaciated diabetics with acidosis showed little or no increase in metabolism. If it is erroneous to apply the surface-area law to an individual normal subject throughout a prolonged fast, it is difficult to see the validity of applying it when there are such marked variations in conditions of nourishment and bodily vigor as exist between the large group of normal persons and the group of emaciated diabetics. We must, however, in this connection, refer to the detailed discussion of the influence of rapid changes in nutritional level upon the basal metabolism on pp. 102-103.

With the fasting individual it is evident that the body-surface law does not obtain. The differences in the fasting man at the beginning and end of the fast are by no means so great as the differences between pathological individuals, including diabetics, and the average normal vigorous individuals from whom the standard of comparison proposed by other writers has been derived.

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[85] Rubner, Arch. f. Hyg., 1908, **66**, p. 89.

[86] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912.

[87] It has been demonstrated that when the diabetics are without acidosis (for example, when following the remarkable Allen treatment), the metabolism is distinctly lower (Joslin, Am. Journ. Med. Sci., 1915, **150**, p. 485) than with acidosis, so that unquestionably the acidosis *per se* materially increases the metabolism.

[88] Lusk, Science, 1911, n. s. **33**, p. 434; *ibid.*, Journ. Biol. Chem., 1915, **20**, p. 599; *Ibid.*, Science, 1915, n. s. **42**, p. 818.

There are even very real purely physical difficulties in the way of assuming that the superficial body-area can be considered a true measure of the heat-loss which is assumed to bear a causal relation to heat-production. Heat-loss does not occur exclusively from the skin. A considerable proportion of the total heat generated is given off from the lungs through the warming of the air and through the vaporization of water. From a large number of experiments with human subjects at rest, either with or without food, it is found that on the average 2.3 per cent of the total heat for 24 hours is required to warm the inspired air; 10 per cent is lost as the result of vaporization of water from the lungs and 12.3 per cent from the vaporization of water from the skin.[89] A recent critical study by Soderstrom and Du Bois [90] indicates that with normal individuals somewhat more than 25 per cent of the total heat is lost in the vaporization of water from the lungs and skin.

Turning from purely experimental tests to those in which the results of experimentation are subjected to statistical analysis, we may first note that the estimates of body-surface area upon which most of the conclusions have been based have been shown to be open to serious criticism. It is to the credit of D. and E. F. Du Bois that they have made possible greater precision in this phase of the work.

In testing by statistical methods the validity of this "law" which has held a conspicuous place in the literature of metabolism for over a quarter of a century, we have started out from two interdependent fundamental assumptions which seem axiomatic.

(*a*) The primary requisite in testing any biological law is to determine quantitatively the degree of interdependence of the magnitudes of the variables which it connects.

(*b*) The true test of the validity of a law is its capacity for predicting an unknown result.

The chief argument used in the past in support of the body-surface law has been that heat-production shows the least variation from individual to individual when expressed in calories per square meter of body-surface. We have shown that this argument is nullified by the simple physical relationship between body-weight and body-surface. The surface areas of similar solids are not directly proportional to their weights, but to the two-thirds powers of their weights. Thus, in a series of individuals whose body-surface area has been determined by the Meeh formula, body-surface area must necessarily be less variable than body-weight. The ratio $\frac{\text{Total heat}}{\text{Body-surface}}$ must, therefore, also be less variable than $\frac{\text{Total heat}}{\text{Body-weight}}$.

Since the body-surface measurements by the Meeh formula and by the Du Bois height-weight chart are very closely correlated, the

[89] Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 476.
[90] Soderstrom and Du Bois, Arch. Intern. Med., 1917, **19**, 946.

same conclusion must also apply for the more modern method of body-surface measurement.

The question as to whether heat-production is more closely related to body-weight or to body-surface can be answered only by (*a*) determining the correlation between each of these two characters and heat-production, or by (*b*) determining which of these two characters will give the closest prediction of the heat-production of an individual.

The correlations between body-weight, body-surface as approximated by the Meeh formula, and body-surface as indicated by the Du Bois height-weight chart on the one hand and gaseous exchange and total heat-production on the other have been determined. The correlations between body-weight and heat-production are of approximately the same magnitude as those between body-surface and heat-production. These results do not, therefore, justify the conclusion that metabolism is proportional to body-surface and not proportional to weight. Metabolism is not proportional to either of these physical characters in an absolute sense. It is correlated very closely indeed with all three bodily measurements, stature, weight, and surface.

While the differences between the constants are very slight and can in no case be looked upon as statistically significant in comparison with their probable errors, the correlation coefficients indicate a somewhat closer relationship between body-surface and total heat-production than between body-weight and total heat-production. That this closer relationship between area and heat-production can not be taken as proof of the validity of "Rubner's law" as applied to human individuals has been indicated. This point will receive attention below.

In the past many physiologists have assumed that the heat-production of an individual should be given by

$$h = w\bar{h}_k$$

where h = the heat-production of the individual, w = the weight of the individual, and $\bar{h}_k$ the mean heat-production per kilogram of body-weight in the standard series, or by

$$h = a\bar{h}_a$$

where a = superficial area and $\bar{h}_a$ = mean heat per square meter of body-area in the standard series.

We have shown that far better results are given by the use of equations of the type

$$(h - \bar{h}) = r_{wh}\frac{\sigma_h}{\sigma_w}(w - \bar{w}) \qquad (h - \bar{h}) = r_{ah}\frac{\sigma_h}{\sigma_a}(a - \bar{a})$$

where h, w, and a denote total heat, body-weight, and surface-area, the bars denote means, the sigmas standard deviations, and r the coefficient of correlation between the characters. When these equations are used the heat-production of an individual can be calculated

from body-weight with essentially the same degree of accuracy as when body-surface is used as a basis of prediction.

Since it has been shown in Chapter IV that both stature and body-weight have independent significance in determining the amount of the metabolism, we have attempted to predict heat-production by the simultaneous use of stature and body-weight.

With such equations the errors of prediction from stature and weight are about the same as when using body-surface as a basis of prediction. Apparently there may be a slight superiority of prediction from body-surface area as estimated from the Du Bois height-weight chart, *especially when the superior methods of prediction by the use of linear equations developed in this volume are employed,* but on the basis of the data at hand this superiority can not be asserted to be more than apparent.

The investigation of the validity of the body-surface law has not merely a theoretical interest but possesses material practical importance. While of recent years Rubner's law has taken on the nature of an empirical formula to be practically applied, in origin it was grounded on the hypothesis that thermogenesis is determined by thermolysis. Or, it was assumed that cooling obtains as a cause of heat-production in the organism. As we look at the matter, the "body-surface law" is at best purely an empirical formula. It has furnished a *somewhat better* basis for the prediction of the metabolism of an unmeasured subject than does body-weight.

The demonstration in the course of this investigation that by the use of proper biometric formulas the metabolism of an individual can be predicted from stature and body-weight with practically the same accuracy as from body-surface area robs "Rubner's law" of its unique empirical significance in clinical and other applied calorimetry. It also casts grave doubts upon any evidence which its superior power of prediction as compared with body-weight may be supposed to furnish in favor of its being a real physiological law.

We have shown that the great supposed difference between body-surface area and body-weight as bases of predicting the metabolism of an unknown subject is largely due to the fact that fallacious methods of calculation have been employed. In so far as body-surface area, as estimated from the Du Bois height-weight chart, has any superiority as a basis of prediction, we believe that this has not been due to any causal relationship between body-surface area as such and metabolism, but that it is merely incidental to the fact that body-surface takes somewhat into account both body-weight and stature, each of which we have shown to have independent significance as proximate factors in determining the total metabolism.

In this volume we have limited our investigation of the body-surface law strictly to its applicability to *variations within the human species,* in short to its *intra-specific* and not its *inter-specific* applicability. It is

proper, however, to point out that since the long existing doubts as to the validity of the older methods for the measurement of body-surface have been fully substantiated by the development of the linear formula of the Du Boises for adults and the photographic method, it is quite possible that more intensive work will draw into question the validity of the surface measurements upon which the evidence of the applicability of the law to animals in general depends. If the errors in the Meeh formula are as large as those pointed out by the Du Boises, one may also reasonably question the formulas for lower animals. It is thus probable that the computations of E. Voit, recently approved by Armsby, will need a radical revision. What influence this revision may have upon the general acceptance of the wider applicability of the so-called body-surface law awaits determination.

Finally, in view of the facts that (*a*) the equations developed in this volume and the convenient tables [91] which have been provided for the prediction of the basal metabolism of the individual from stature, weight, and age deprive the "body-surface law" of its unique practical significance, and that (*b*) the evidence of an actual physiological nexus between body-surface area and metabolism is altogether inconclusive, it seems to us that the "body-surface law," as far as its supposed application to the human individual is concerned, must play a very minor rôle indeed in future physiological discussions.

The equations which we have given were designed primarily for the most exact work in the problem of metabolism during the period of adult human life. While for this period they are decidedly superior to prediction by means of the average heat production per unit of body surface in a standard series we would not at present recommend the discarding of the older methods of correcting for body size in comparative studies of metabolism.

Body-weight, the two-thirds power of body-weight, and the more recent attempts at actual surface measurement must be considered in comparing organisms of very different physical configuration. We must, however, point out that our experience with the "body-surface law" in its application to the human individual indicates that extraordinary caution must be used in regard to all of these methods. Eventually they will probably have to be replaced by standards similar to those developed for human adults in this volume.

Until this can be done on the basis of adequate physical and experimental data we do not desire to have our results for adults generalized beyond the range of physical characters and age to which we have ourselves applied them. If this were done they might tend to hinder rather than to assist in the advancement of research. For the present at least, the older methods of comparison must still be appealed to in the inter-specific comparisons.

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[91] See Chapter VIII for a full discussion of these tables.

CHAPTER VII.

A COMPARISON OF BASAL METABOLISM OF NORMAL MEN AND WOMEN.

1. HISTORICAL.

Consideration of the problem of the relative metabolism of men and women dates from 1843, when Scharling,[1] whose results have been recalculated by Sondén and Tigerstedt,[2] found that a girl 19 years of age excreted a considerably smaller amount of carbon dioxide and a considerably smaller amount of carbon dioxide per kilogram of body-weight than a boy 16 years of age. Her actual carbon-dioxide production was less than that of two men of 28 and 35, but her carbon dioxide per kilogram of body-weight lay between that of the two adult men. He also found that a girl of 10 produced both absolutely and relatively less carbon dioxide than a boy of about the same age. Scharling concludes from these observations that there is a greater production of carbon dioxide by men than by women of the same age.

Andral and Gavarret [3] worked with 37 men and 22 women. They conclude that throughout the whole of life there is a greater production of carbon dioxide by men than by women, and that between the ages of 16 and 40 men produce about twice as much carbon dioxide as women do. Unfortunately Andral and Gavarret have not recorded the weights of their men and women; it is therefore, impossible to make comparisons on the basis of relative heat-production, *i.e.*, on the number of calories per kilogram of body-weight or on the basis of the number of calories per square meter of body-surface.

The data of Speck,[4] restated by Sondén and Tigerstedt,[5] show higher metabolism in men than in women over 17 years of age, but the difference is reversed in the case of a boy of 10 and a girl of 13.

In their classical monograph on the respiratory exchange and metabolism, Sondén and Tigerstedt [6] published an extensive series of observations on both men and women, in which the large respiration chamber in Stockholm was used. These results are comparable for the two sexes, although the observations were made under such conditions

[1] Scharling, Ann. d. Chem. u. Pharm., 1843, **45**, p. 214. Reprinted in detail in Ann. de chim. et phys., 1843, 3 sér., **8**, p. 478.
[2] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, **6**, p. 54.
[3] Andral and Gavarret, Ann. d. chim. et phys., 1843, 3 sér., **8**, p. 129.
[4] Speck, Physiologie des menschlichen Athmens, Leipzig, 1892.
[5] Sondén and Tigerstedt, *loc. cit.*, p. 57.
[6] Sondén and Tigerstedt, *loc. cit.*, p. 58.

as to exclude them for use as indices of basal metabolism. These authors based their comparisons on the carbon-dioxide excretion per hour per kilogram of body-weight and per square meter of body-surface. They express the relationship between the gaseous exchange of men and women as a proportion. Their end results are summarized in table 76. They conclude that in youth the carbon-dioxide production of boys is considerably greater than that of girls of about the same age and body-weight, but with increasing age this difference gradually becomes less and less, and finally in old age it disappears entirely. It must be noted here that the authors specifically state that it appears to them that new experiments are necessary before this problem can be completely solved.

Table 76.—*Comparison of carbon-dioxide production in men and women: data of Sondén and Tigerstedt.*

Age of males.	Age of females.	CO_2 per kilogram per hour, males.	CO_2 per kilogram per hour, females.	Relative CO_2 production per kilogram.	CO_2 per hour per square meter, males.	CO_2 per hour per square meter, females.	Relative CO_2 production per square meter.
7	7	1.149	1.133	100 : 101	26.27	26.61	100 : 99
9	9	1.207	0.850	100 : 142	26.89	20.78	100 : 144
10 to 11	11	1.085	0.845	100 : 131	27.88	21.75	100 : 128
12	12	0.997	0.743	100 : 134	26.49	20.14	100 : 132
13 to 14	14	0.980	0.661	100 : 148	27.12	18.22	100 : 149
15	15	0.813	0.601	100 : 135	23.54	17.16	100 : 137
17	17, 30	0.814	0.522	100 : 156	24.18	15.53	100 : 156
30 to 50	40 to 50	0.499	0.554	100 : 90	16.55	17.94	100 : 90
57	65	0.407	0.390	100 : 104	14.24	12.64	100 : 113

In 1899 Magnus-Levy and Falk [7] published an extended series of observations on both men and women in which the Zuntz-Geppert respiration apparatus was employed. Although Johannson [8] had shortly before emphasized the importance of controlling muscular repose and had outlined his experience in the voluntary exclusion of muscular activity, these observations of Magnus-Levy and Falk represent the first comparative observations made upon both men and women in which particular attention was given to complete muscular rest; hence they are more nearly comparable with our experiments than any series published previous to 1899. The series with men comprise observations on 16 boys, 10 men between 22 and 56 years of age, and 5 men 64 years old and over. The series of women include observations on 9 girls, 15 women between 17 and 57, and 7 women of 71 years or older. The data as to age, weight, and height are recorded. The authors have likewise computed the values per kilogram per minute and per square meter of body-surface per minute. In their comparisons of the values obtained with men and women on the basis

[7] Magnus-Levy and Falk, Arch. f. Anat. u. Physiol., Physiol. Abt., Suppl., 1899, p. 314.
[8] Johannson, Skand. Arch. f. Physiol., 1898, **8**, p. 85.

of body-weight, they conclude that in middle life the gaseous metabolism of women is approximately the same as that of men of the same age and body-weight. With children and old men and women, the females have a slightly less (5 per cent) metabolism than the men. The authors also point out that, owing to the larger proportion of body-fat, women would have a metabolism per unit of active protoplasmic tissue greater than would men.

Following the work of Magnus-Levy and Falk there was a period of about 16 years in which little was done on the problem of the differences in the metabolism of men and women. Many observations were made on men, but there were relatively few determinations of basal metabolism on normal women. In 1915, however, Benedict and Emmes[9] returned to the problem, basing their calculations on the 89 men and the 68 women designated as the original Nutrition Laboratory series. In this study they introduced what we have here called the selected-group method of comparison, a method which marked a distinct advance in the comparison of the metabolism of classes of individuals. This method, in a somewhat modified form, we shall employ extensively in this chapter.

2. COMPARISON OF METABOLISM OF MEN AND WOMEN ON THE BASIS OF GENERAL CONSTANTS.

In this section we shall base our comparisons of the basal metabolism of the sexes upon the constants for the series of individuals as a whole. This method of testing the existence of a sexual differentiation in metabolic activity is not, in our opinion, so valuable as the further development of the selected-group method of Benedict and Emmes in the following section. For the sake of completeness, however, both methods of analysis must be employed.

Consider, first, the average gross heat-production in calories per 24 hours in series of adults. For the 72 individuals of the Gephart and Du Bois selection, the 64 others, and the 136 men the averages are 1623, 1641, and 1632 calories, respectively. For the 68 original, the 35 supplementary, and the total 103 women the daily heat-productions are 1355, 1339, and 1349 calories, respectively. Thus the heat-production of the average woman is roughly 300 calories per day less than that of the average man, when both are measured in muscular repose and at a period 12 hours after the last meal. Thus in adults *gross* metabolism is markedly less in women than in men. Note, however, that these values are uncorrected for weight, stature, and age in both sexes.

But women are on the average smaller than men. In either sex large individuals produce on the average more heat than smaller ones. In any discussion of the relation of metabolism to sex it is necessary to correct for this difference in size. Turning to average heat-produc-

[9] Benedict and Emmes, Journ. Biol. Chem., 1915, **20**, p. 253.

tion per unit of body-weight or body-surface, we note that in the 72 men constituting the Gephart and Du Bois selection the average heat-production is 25.8 calories per kilogram of body-weight, in the 64 other men it is 25.6 calories, while for the total 136 men it is 25.7 calories. In the 68 original women it is 25.4 calories, in the 35 supplementary women it is 22.7 calories per kilogram, while in the whole series of 103 women it is 24.5 calories.

On the basis of body-surface area the average heat-productions per square meter as estimated by the Meeh formula are 832 calories in the Gephart and Du Bois selection, 828 calories in the 64 men not included in the Gephart and Du Bois selection, and 830 calories in the whole series of 136 men. The comparable values for the women are 772 calories for the 68 original women, 715 calories for the 35 supplementary women, and 753 calories for the whole series of 103 women.

With the measurement of body-surface area furnished by the height-weight chart we find average heat-productions per square meter of body-surface area of 927 calories for the Gephart and Du Bois selection, 924 calories for the 64 other men, and 925 calories for the whole series of men. For women the values are 865 calories for the 68 original women, 820 calories for the 35 supplementary women, and 850 calories for the whole series.

If we extend the comparison to the 8 men and 7 women studied by Palmer, Means, and Gamble,[10] we find that the average daily heat-production of men is 1657.4 calories, whereas in women it is 1468.7 calories. In men the average heat-production per kilogram of body-weight for a 24-hour period is 23.36 calories, whereas in women it is 21.77 calories. Expressing heat-production in calories per square meter of body-surface per 24 hours we find that the results for men and women stand in the ratio 784 : 718 calories when surface is estimated by the Meeh formula and in the ratio 941 : 919 calories when surface is estimated by the Du Bois method. These results, due to the experience of other investigators, will be tested by other criteria on p. 217, and shown to be in full accord with our own findings throughout.

It is now desirable to look at the evidence from a quite different angle. Instead of depending upon average heat-production or average heat-production per unit of body-weight or body-surface for a basis of comparison of men and women, we may inquire what amount of change in heat-production would be associated with a variation of a definite amount from the mean body-weight or the mean body-surface in the two sexes. If women show a smaller change in heat-production associated with a variation of the same amount in a physical dimension we must conclude that metabolism is less in women than in men. If we consider these variations in quantity of heat set free per unit of body-

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[10] Palmer, Means, and Gamble, Journ. Biol. Chem., 1914, **19**, p. 239; Means, *ibid.*, 1915, **21**, p. 263.

weight or body-surface we note from equations on page 170 that in the 72 individuals of the Gephart and Du Bois selection heat-production increases 16.7 calories per 24 hours for each increase of 1 kilogram of body-weight above the average. In the 64 men not included in the Gephart and Du Bois selection the increase is 15.4 calories. In the 136 men it is 15.8 calories. For comparison we note that in the 68 original women the increase is 10.5 calories, in the supplementary series it is 6.3 calories, and in the whole series of women it is 8.2 calories.

Turning to the change in heat-production with variation in body-surface, we note from the variable term of the appropriate equations (page 170) that the change for body-surface as measured by the height-weight chart is very different from that for body-surface as measured by the Meeh formula. Working, therefore, with each of the two formulas separately, we find that with surface measured by the Meeh formula the two groups of men show a change of 822 and 764 calories for a variation of 1 square meter of body-surface, while for the 136 men the change is 783 calories. In the 68, 35, and 103 women the values are 506, 316, and 400 calories respectively.

When superficial area is measured by the height-weight chart the change in heat-production for a variation of 1 square meter of body-surface is 1026, 1101, and 1070 calories in the 72, 64, and 136 men of the three groups compared, whereas in the groups of 68, 35, and 103 women the values are 808, 500, and 639 calories respectively.

Turning back to the diagrams of preceding chapters showing the heat-production of subgroups of men and women, we note that the smoothed averages, and generally the actually observed averages as well, are higher in men than in women. This is clearly shown in diagrams 13 and 17 of Chapter IV, in which the individuals are arranged according to stature and according to body-weight.

Again in diagrams 20–22 of Chapter V, showing the gross heat-production and heat-production per unit of body-weight and body-surface in men and women of different ages, the lines for the men are consistently higher than those for the women. The same is true, with few exceptions, of the empirical means.

Now the highly important result of all these methods of comparison is this: Without exception the tests based on general population constants indicate higher metabolism in the man.

3. COMPARISON OF METABOLISM OF MEN AND WOMEN BY USE OF GRADUATION EQUATIONS.

We now turn to a comparison of men and women on the basis of a method which is in essence an extension and modification of the selected-group method of Benedict and Emmes.[11] Instead of comparing the

[11] Benedict and Emmes, *loc. cit.* Magnus-Levy and Falk, *loc. cit.*, used essentially the selected-group method but with wholly inadequate data.

averaged constants of a group of women with the empirical average of a group of men selected for their approximate agreement in stature and body-weight, we compare the averages for the groups of women selected for stature, body-weight, or both stature and body-weight, or for stature, body-weight, and age with the *smoothed* or theoretical averages for men of the specified physical dimensions.

The method is essentially the same as that which has been followed in certain preceding sections. We calculate the theoretical heat-production of female individuals from constants based on the series of men, and by comparison of the empirical means with the average of the theoretical values we determine whether the women have a higher or a lower metabolism than would be expected if they were men of the same physical dimensions.

For a first test of the existence of sexual differentiation we classify the women according to (*a*) body-surface area as determined from the Du Bois height-weight chart, (*b*) body-weight, (*c*) stature, and (*d*) age.

The predicted total heat-production has been estimated by means of the regression equations for total heat on physical characters and age in the total male series.[12]

In using these equations we have started from the simplest and advanced to the more complex, laying the results attained by each of the methods before the reader, who may therefore trace the growth of the underlying conceptions of our methods and convince himself that the results due to the more complicated processes are not attributable to some error in the more recondite reasoning. We first of all compare the values of the metabolism constants actually obtained for women with those which are calculated from their weight, from their stature, and from their body-surface area considered independently of each other and of age. Thus in working with body-surface we determine whether women as a class have a higher or a lower basal metabolism than men of the same superficial area. In doing this we disregard body-weight, stature, and age. Similarly, in dealing with equations involving constants for body-weight we disregard stature, body-surface, and age.

In the second attack upon the problem we base our predictions of heat-production in women upon an equation involving the constants for body-weight and stature in men. Thus body-surface (which is of course largely determined by stature and weight) and age have been disregarded.

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[12] The analysis in Chapter VI has fully demonstrated the fallacy of predicting total heat-production by multiplying body-weight or body-surface by the average heat-production per unit weight or per unit surface in the standard series. We shall not, therefore, give the results of comparison on that basis further than to say that with individuals grouped according to body-weight and body-surface area, as in tables 80 and 81, the average actual heat-production of the groups of women is lower than that based on male constants in all the 12 subgroups classified with respect to body-surface and lower than that calculated from the average production per kilogram of body-weight in the men in 10 of the 13 groups of women classified according to body-weight.

Finally we have employed an equation in which prediction of heat-production is made from weight, stature, and age.

The characteristic equations for the calculation of total heat-production from age, surface, weight, and stature considered alone are:

$$h = 1823.80 - 7.15\,a \qquad h = 617.493 + 15.824\,w$$
$$h = -254.546 + 1070.454\,a_D \qquad h = -1237.637 + 16.589\,s$$

where h = total heat, a = age, a_D = body-surface area by the Du Bois height-weight chart, w = body-weight, and s = stature.

Employing these equations, we have calculated the theoretical heat-production of each individual woman on the assumption that she is a man of like character. The difference between her observed metabolism (24-hour period) and her theoretical metabolism has then been determined by taking

(measured metabolism) *less* (theoretical metabolism)

Thus a negative sign denotes a deficiency in the actual as compared with the normal heat-production.

TABLE 77.—*Differences in the metabolism of men and women, women classified according to age.*

Age.	N	Mean total heat-production.	Prediction from age.			Prediction from weight and stature.			Prediction from weight, stature, and age.		
			Mean predicted total heat.	Actual less predicted.	Percentage difference.	Mean predicted total heat.	Actual less predicted.	Percentage difference.	Mean predicted total heat.	Actual less predicted.	Percentage difference.
15 to 19	12	1371.4	1698.0	−326.6	19.2	1392.9	− 21.5	1.5	1464.7	− 93.3	6.4
20 to 24	35	1370.9	1666.1	−295.2	17.7	1444.3	− 73.3	5.1	1487.1	−116.2	7.8
25 to 29	20	1334.7	1635.6	−300.9	18.4	1399.9	− 65.2	4.7	1412.0	− 77.3	5.5
30 to 39	13	1347.3	1569.2	−221.9	14.1	1466.6	−119.2	8.1	1416.6	− 69.3	4.9
40 to 54	13	1368.0	1487.2	−119.2	8.0	1600.2	−232.2	14.5	1479.3	−111.3	7.5
55 to 74	10	1253.1	1379.3	−126.2	9.1	1540.1	−287.0	18.6	1313.2	− 60.1	4.6

In basing our conclusions concerning the existence of a sexual difference in metabolism upon these differences we have examined them in three ways: (*a*) We have compared the average values of observed and theoretical metabolism in groups of women classified with respect to age, stature, body surface, and weight. (*b*) We have compared the average values of observed and of theoretical heat-production in groups of individuals classified by both stature and body-weight. Finally, (*c*) we have arranged the differences in order according to sign and magnitude and considered the evidence furnished by the frequency distributions of the individual deviations.

The results of a comparison of the total heat-productions with those computed from age and classified according to the age of the women are shown in the first panel of table 77. The differences are without exception negative in sign, thus indicating that the metabol-

ism of the women is lower than it would be in men of the same age if physical differences were disregarded. The differences range from 119.2 to 326.6 calories, or from 8.0 to 19.2 per cent. The results are represented graphically in the lower figure, A, of diagram 27. In this and the following four diagrams the upper row of dots represents the theoretical and the lower row the actually observed average basal metabolism for the groups of individuals.[13]

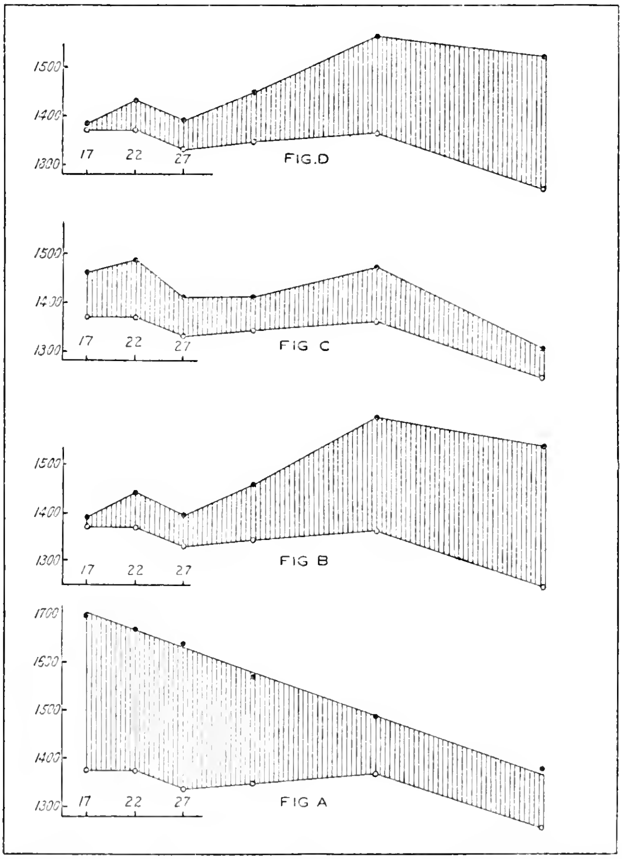

DIAGRAM 27.—Comparison of metabolism of men and women. Women classified according to age.

The differences between the theoretical and the actual heat-production is not as great in the older groups of women as in the younger. This point will be touched upon later.

[13] In this and the following diagrams the theoretical heat-productions calculated from the linear equations should of course lie in a straight line except for the divergences due to the deviations of the individuals in the subgroups from the mid-ordinate values for age, stature, body-weight, and body-surface due to the errors of random sampling. The remarkable agreement of the best-fitting straight line and the calculated mean theoretical heat-production of the several groups of women furnishes a most gratifying justification of the system of grouping adopted.

For the sake of a further comparison on the basis of an age grouping of the women we have used the metabolism calculated from the equation for the regression of heat-production on body-surface as estimated by the Du Bois height-weight chart in the men. The comparison is made in table 78. The results, which are represented graphically in the uppermost figure, D, of diagram 27, fully confirm the preceding. Without exception the groups of women show average values of metabolism from 13 to 273 calories or from about 1 to 18 per cent lower than values computed on the assumption that their heat-production is identical with that of men of like weight, stature, and age.

TABLE 78.—*Differences in the metabolism of men and women, women classified according to age.*

Age.	N	Mean total heat-production.	Prediction from body-surface.		
			Mean predicted total heat.	Actual less predicted.	Percentage difference.
15 to 19	12	1371.4	1384.1	− 12.7	0.9
20 to 24	35	1370.9	1432.2	− 61.3	4.3
25 to 29	20	1334.7	1391.8	− 57.1	4.1
30 to 39	13	1347.3	1454.2	−106.9	7.4
40 to 54	13	1368.0	1568.6	−200.6	12.8
55 to 74	10	1253.1	1525.6	−272.5	17.9

TABLE 79.—*Differences in the metabolism of men and women, women classified according to stature.*

Stature.	N	Mean total heat-production.	Prediction from stature.			Prediction from weight and stature.			Prediction from weight, stature, and age.		
			Mean predicted total heat.	Actual less predicted.	Percentage difference.	Mean predicted total heat.	Actual less predicted.	Percentage difference.	Mean predicted total heat.	Actual less predicted.	Percentage difference.
149 to 151	2	1259.5	1267.0	− 7.5	0.6	1295.0	− 35.5	2.7	1335.0	− 75.5	5.7
152 to 154	6	1315.7	1300.7	+ 15.0	1.2	1327.2	− 11.5	0.9	1374.6	− 58.9	4.3
155 to 157	14	1310.8	1353.9	− 43.1	3.2	1352.4	− 41.6	3.1	1346.5	− 35.7	2.7
158 to 160	18	1298.2	1403.9	−105.8	7.5	1407.8	−109.6	7.8	1406.0	−107.8	7.7
161 to 163	24	1375.8	1450.7	− 75.0	5.2	1478.7	−103.0	7.0	1445.4	− 69.6	4.8
164 to 166	19	1367.3	1494.4	−127.1	8.5	1531.5	−164.2	10.7	1494.1	−126.8	8.5
167 to 169	12	1379.0	1550.7	−171.7	11.1	1532.7	−153.7	10.0	1503.4	−124.4	8.3
170 to 172	6	1413.2	1591.0	−177.8	11.2	1545.2	−132.0	8.5	1513.8	−100.6	6.6
173 to 175	1	1430.0	1666.0	−236.0	14.2	1561.0	−131.0	8.4	1580.0	−150.0	9.5
176 to 178	1	1383.0	1682.0	−299.0	17.8	1894.0	−511.0	27.0	1786.0	−403.0	22.6

The results of a comparison of the actual heat-production in the women with that computed from stature in groups of women classified with respect to stature are shown in table 79. With one single exception, that of the 6 subjects 152 to 154 cm. in height, the women of each grade of stature show a smaller actual average metabolism than that computed on the assumption that they were men of like stature. The lower figure, A, in diagram 28, which represents these results brings

out clearly the difference between the actual metabolism in women and the metabolism which would be found in men of the same stature. The width of the shaded zone increases from the lower to the higher statures. Thus the taller women show a greater deficiency in their metabolism than the shorter ones.

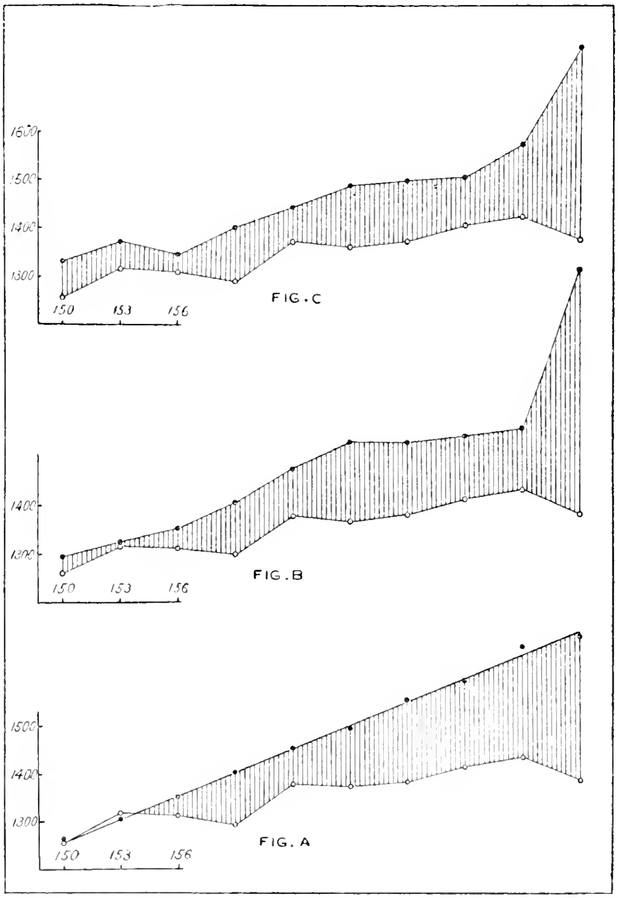

DIAGRAM 28.—Comparison of metabolism of men and women. Women classified according to stature.

Calculating the total heat-production of the women from the equations for the regression of total heat-production on body-surface in men, and classifying with respect to body-surface, we have the mean calculated and the mean actual heat-production in the first section of table 80.

Again the actual heat-productions of the women are without exception lower than those which they would have if they were men of like body-surface area.

The graphic representation of the results for the grouping by surface area in the lowermost figure, A, of diagram 29, shows a deficiency in metabolism throughout the whole range of variation in body-surface area. Apparently the difference between the actual and the computed metabolism is greater in the women of larger as compared with those of smaller area.

TABLE 80.—*Differences in the metabolism of men and women, women classified according to surface.*

Body-surface.	N	Mean total heat-production.	Prediction from body-surface.			Prediction from weight and stature.			Prediction from weight, stature, and age.		
			Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.	Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.	Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.
1.28 to 1.34	1	985.0	1137.0	−152.0	13.4	1167.0	−182.0	15.6	1005.0	− 20.0	2.0
1.35 to 1.41	9	1191.8	1223.9	− 32.1	2.6	1246.2	− 54.4	4.4	1257.2	− 65.4	5.2
1.42 to 1.48	13	1276.1	1299.3	− 23.2	1.8	1313.6	− 37.5	2.9	1294.1	− 18.0	1.4
1.49 to 1.55	26	1285.1	1371.0	− 85.8	6.3	1380.8	− 95.7	6.9	1390.5	−105.4	7.6
1.56 to 1.62	18	1368.4	1443.8	− 75.4	5.2	1450.6	− 82.2	5.7	1439.4	− 71.0	4.9
1.63 to 1.69	11	1463.4	1514.5	− 51.2	3.4	1518.5	− 55.1	3.6	1526.5	− 63.1	4.1
1.70 to 1.76	12	1447.0	1592.1	−145.1	9.1	1599.7	−152.7	9.5	1552.0	−105.0	6.8
1.77 to 1.83	7	1416.6	1657.0	−240.4	14.5	1677.0	−260.4	15.5	1566.7	−150.1	9.6
1.84 to 1.90	1	1334.0	1769.0	−435.0	24.6	1797.0	−463.0	25.8	1621.0	−287.0	17.7
1.91 to 1.97	2	1673.5	1822.5	−149.0	8.2	1895.0	−221.5	11.7	1965.0	−291.5	14.8
1.98 to 2.04	3	1521.7	1890.0	−368.3	19.5	1945.7	−424.0	21.8	1834.3	−312.6	17.0

TABLE 81.—*Differences in the metabolism of men and women, women classified according to body-weight.*

Body-weight.	N	Mean total heat-production.	Prediction from body-weight.			Prediction from stature and weight.			Prediction from weight, stature, and age.		
			Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.	Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.	Mean predicted total heat.	Actual less predicted.	Per-cent-age differ-ence.
34.6 to 39.5	2	1063.0	1195.0	−132.0	11.0	1203.0	−140.0	11.6	1060.5	+ 2.5	0.2
39.6 to 44.5	8	1197.9	1284.0	− 86.1	6.7	1253.4	− 55.5	4.4	1264.8	− 66.9	5.3
44.6 to 49.5	18	1255.8	1370.4	−114.6	8.4	1324.8	− 69.0	5.2	1308.8	− 53.0	4.0
49.6 to 54.5	27	1303.8	1441.3	−137.6	9.5	1400.5	− 96.7	6.9	1411.0	−107.2	7.6
54.6 to 59.5	19	1422.2	1525.1	−102.9	6.8	1477.9	− 55.7	3.8	1484.9	− 62.7	4.2
59.6 to 64.5	11	1449.2	1597.7	−148.5	9.3	1552.5	−103.3	6.7	1552.9	−103.7	6.7
64.6 to 69.5	4	1491.3	1677.5	−186.3	11.1	1628.5	−137.3	8.4	1552.0	− 60.7	3.9
69.6 to 74.5	7	1381.7	1745.7	−364.0	20.9	1658.0	−276.3	16.7	1502.8	−121.1	8.1
74.6 to 79.5	1	1334.0	1861.0	−527.0	28.3	1797.0	−463.0	25.8	1621.0	−287.0	17.7
79.6 to 84.5	2	1494.5	1905.0	−410.5	21.5	1817.0	−322.5	17.7	1728.0	−233.5	13.5
84.6 to 89.5	1	1591.0	2015.0	−424.0	21.0	1873.0	−282.0	15.1	1944.0	−353.0	18.2
89.6 to 94.5	3	1646.0	2083.7	−437.7	21.0	1953.3	−307.3	15.7	1901.0	−255.0	13.4

The results of predicting the total heat-production of women from the regression of total heat on body-weight in men are shown in comparison with the average actual heat-productions of women in the first section of table 81.

In every group the observed total production of the women is distinctly lower than it would be if the group were composed of men of like body-weight.

The graphic representation of these results for grouping by body-weight in the lowermost figure, A, of diagram 30, shows the widest divergence of the actual from predicted heat-productions found in any of

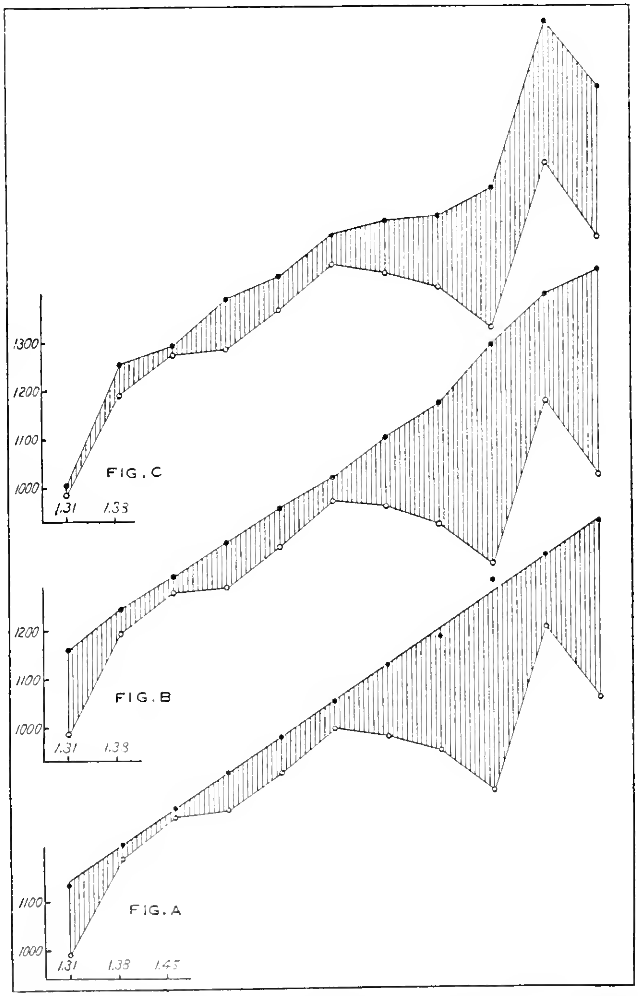

DIAGRAM 29.—Comparison of metabolism of men and women. Women classified according to body-surface.

the four groupings, *i.e.*, by age, stature, body-surface, and body-weight. The discrepancy is particularly great in the case of the heavier women.

The largest divergence between the theoretical and the actual heat-productions is found when the theoretical values for the women are computed by assuming that the heat-production of a woman should

be the same as that of a man of like weight. The greatest increase in the amount of divergence between the theoretical and the actual heat-production is apparently found toward the upper limit of the range of the bases of classification. It seems reasonable, therefore, to assume (as a working hypothesis for further investigation) that body-weight

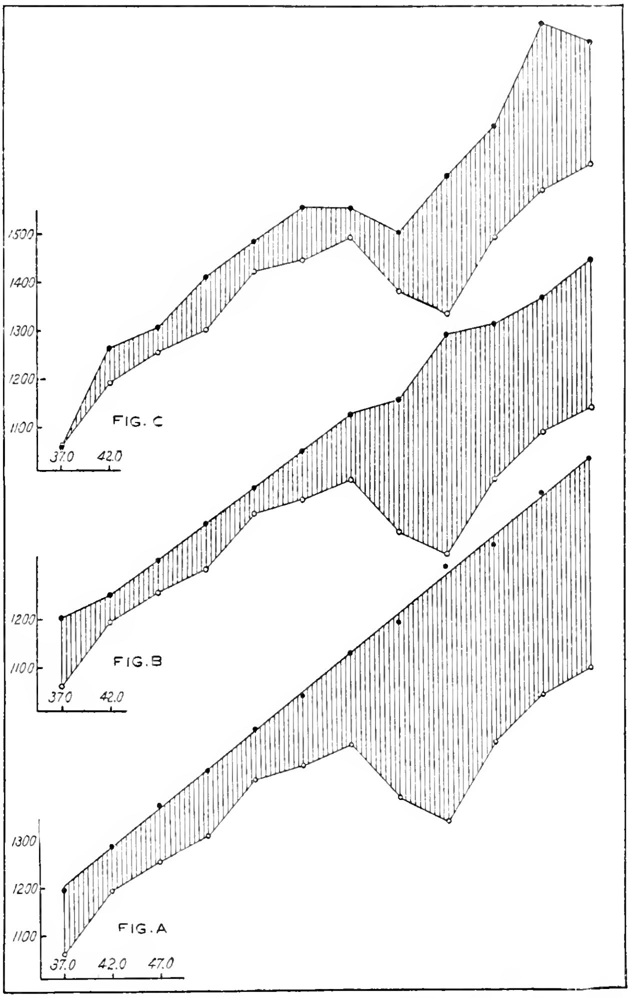

DIAGRAM 30.—Comparison of metabolism of men and women. Women classified according to body-weight.

rather than stature or body-surface is the primary proximate factor in bringing about this observable tendency for the women with greater stature and greater body-surface to show a relatively greater deficiency in metabolism. If this view be correct, the observed relationships for stature and body-surface would be the resultant of this primary interrelationship and the correlations of both stature and area with weight.

We now apply a further test of the existence of a sexual differentiation with respect to metabolic activity in the human adult. In Chapter VI the value of multiple-regression equations, involving both stature and body-weight, for purposes of prediction has been conclusively demonstrated. We may now make use of equations of this type for predicting the amount of heat in calories per 24 hours which a woman would produce if she were a man of the same stature and body-weight. We shall thus avail ourselves of all the advantages of the selected-group method employed in earlier papers from the Nutrition Laboratory,[14] but by the use of suitable statistical methods shall avoid certain real difficulties encountered, but not overcome, by them.

What we have done is in effect this: We have expressed the relationship between heat-production and stature and weight in men as a mathematical plane, the coördinates of which give the most probable heat-production in individuals of any combination of stature and weight. Using this plane to predict the heat which a woman of given weight and stature would produce *if she were a man*, we have a series of check or control values which is free from the disadvantages of the empirical selected-group system.

Using the equation

$$h = -314.613 + 13.129\,w + 6.388\,s$$

based on men we have computed the theoretical heat-production for each woman.

We have treated the differences between the actual and the calculated heat-production in three ways.

The distribution of the deviation of the actual heat-production of each woman from her computed production is shown in table 84, to be discussed below.

The mean theoretical and actual heat-productions for groups of individuals classified by age, stature, body-surface by the Du Bois height-weight chart, and body-weight have been calculated, and the differences between theoretical and actual heat-production are recorded under the caption "Prediction from weight and stature" in tables 77, 79, 80, and 81.

Without a single exception the 39 comparisons indicate a lower metabolism in women. The differences between observed and theoretical values range from 1.5 to 18.6 per cent in the case of groups classified according to age, from 0.9 to 27.0 per cent in the case of women grouped according to stature, from 2.9 to 25.8 per cent in the case of subjects arranged according to their body-surface, and from 3.8 to 25.8 per cent in the case of groups of women assembled on the basis of body-weight.

[14] Benedict and Emmes, *op. cit.*

These results are expressed graphically in the second figure, B, of diagrams 27 to 30. These figures differ from those representing prediction from linear equations (A) in that the mean theoretical heat-productions do not lie in sensibly a straight line. The discrepancy is especially great in the classification by stature, where the disturbing influence of weight is very obvious.

The difference between the graphs for body-weight and body-surface area is not quite so clearly marked as in the case of the linear equations, but the more conspicuous deficiency in the metabolism of the heavier women is manifest.

The results fully confirm the analysis on the basis of the linear equations.

We now turn to the results secured when age as well as body-weight and stature is taken into account in determining the theoretical heat-productions of the women. The equation, based on the 136 men, is

$$h = 66.4730 + 13.7516\,w + 5.0033\,s - 6.7550\,a$$

By the evaluation of this equation for each woman by inserting her weight w, stature s, and age a, we obtain her probable heat-production on the assumption that she is a man of like weight, stature, and age.

A comparison of the calculated average heat-productions of women grouped by age, weight, body-surface, and by stature is made in the final sections of tables 77, 79, 80, and 81.

With one exception—that of the lowest-weight group containing only 2 women—which is numerically insignificant, the 39 comparisons indicate that the actual heat-production is lower than it would be if these individuals were men of the same age, stature, and body-weight. The amount by which the women fall short of their computed metabolism is measured by differences ranging from 4.9 to 7.8 when the classification is on an age basis, from 2.7 to 22.6 when grouping is made by stature, from 1.4 to 17.7 when body-surface serves as a basis of classification, and (disregarding the one exceptional case) from 3.9 to 18.2 per cent when the women are thrown into groups of like body-weight.

The results are represented graphically in the third figure, *C*, of diagrams 27 to 30. Correction for age has perhaps tended to reduce slightly the differences between the observed and predicted-heat productions, but (with the one slight exception already noted) they are nevertheless conspicuous and persistent throughout the whole range of whatever scale of classification is employed.

The reader will note that when the correction for age, stature, and weight is made and the individuals are classified by age, the theoretical and the empirical heat-productions are separated by roughly the same distance throughout the whole age range.

As far as this method of analysis is concerned, more conclusive proof of the existence of a sexual difference in the metabolism of male

and female adults could not be obtained. We now turn to another method of analysis.

For purposes of comparison by group averages we have classified the women in a table of double entry, table 82. The entries with signs in this table are the differences between the theoretical and the actual average heat-productions for the groups of individuals having the weights and statures, indicated by the marginal columns. The differences are given in calories and in the average percentage of the computed heat-production of each individual. The percentages follow the

TABLE 82.—*Differences in metabolism of men and women, women classified according to stature and weight.*

Weight in kilograms.	Stature in centimeters.					General averages.
	149 to 157.	158 to 160.	161 to 163.	164 to 166.	167 to 178.	
34.6 to 44.5	− 76.6= 6.4 **− 84.6= 6.7** $N=5$	− 48.5= 3.8 **− 67.5= 5.2** $N=2$	.... $N=0$	−131.0=10.1 **− 53.0= 4.3** $N=1$	− 56.5= 4.5 **+ 40.0= 3.4** $N=2$	− 72.4= 5.9 **− 53.1= 4.1** $N=10$
44.6 to 49.5	− 61.4= 4.7 **− 6.66= 5.1** $N=7$	− 6.2= 0.4 **− 32.6= 2.3** $N=5$	− 32.0= 2.4 **− 64.0= 4.6** $N=2$	−172.0=12.6 **± 00.0= 0.3** $N=3$	− 201.0=14.7 **−198.0=14.5** $N=1$	− 69.0= 5.1 **− 53.5= 3.9** $N=18$
49.6 to 54.5	− 39.5= 2.9 **− 53.5= 3.8** $N=4$	− 102.2= 7.4 **−148.2=10.5** $N=6$	− 90.8= 6.4 **− 75.7= 5.4** $N=9$	− 105.0= 7.4 **− 129.3= 8.8** $N=6$	− 196.5=13.4 **−168.5=11.8** $N=2$	− 96.7= 6.8 **−107.3= 7.5** $N=27$
54.6 to 59.5	+ 48.3= 3.2 **+ 9.0= 0.4** $N=4$	− 222.0=15.1 **−209.0=14.4** $N=2$	− 91.0= 6.3 **− 38.6= 2.6** $N=5$	− 44.0= 2.9 **− 94.0= 6.1** $N=3$	− 44.2= 2.9 **− 67.2= 4.3** $N=5$	− 55.7= 3.8 **− 62.8= 4.2** $N=19$
59.6 to 69.5	+ 189.0=12.8 **+125.0= 8.1** $N=1$	.... $N=0$	−103.7= 6.7 **− 38.5= 2.3** $N=6$	− 165.0=10.5 **−187.0=11.7** $N=1$	− 155.3= 9.7 **−155.9= 9.7** $N=7$	−112.3= 7.0 **− 92.3= 5.7** $N=15$
69.6 to 94.5	−134.0= 7.7 **− 64.0= 3.8** $N=1$	− 263.0=15.9 **−112.0= 7.0** $N=3$	− 256.5=14.6 **−220.0=11.2** $N=2$	− 309.4=16.9 **−222.4=12.7** $N=5$	− 421.0=23.3 **−256.0=15.2** $N=3$	− 303.3=17.1 **−194.3=11.3** $N=14$
General averages.	− 32.9= 2.7 **− 45.7= 3.6** $N=22$	− 109.7= 7.3 **−107.8= 7.5** $N=18$	−103.0= 6.8 **− 69.7= 4.5** $N=24$	− 164.3=10.3 **−126.8= 7.9** $N=19$	− 163.9=10.1 **−132.5= 8.3** $N=20$	−112.3= 7.3 **− 94.0= 6.2** $N=103$

equality sign. A negative sign indicates that the women show a lower heat-production than would men of like characteristics. The theoretical heat-productions were calculated in two ways. The entries with signs in ordinary type are the differences between the observed and the theoretical heat-productions when the latter are computed from weight and stature only. The entries with signs in black-faced type are the differences between the actual and the theoretical heat-productions when the latter are calculated from weight, stature, and age.

In arranging the data for this table the individuals have been assembled into somewhat larger and more arbitrarily limited groups for both stature and weight than when they were classified with respect

to one of these physical characters merely. This has been necessary in order to secure a number of individuals in the several compartments of the table. With the grouping of weight and stature adopted in the accompanying table, 28 of the 30 different combinations of stature and weight are represented by from 1 to 9 individuals each. When the theoretical heat-productions are computed from weight and stature, 26 of the 28 groups of women classified with regard to both stature and weight show lower average heat-productions than they would if they were composed of men falling in the same range of stature and weight. When weight, stature, and age are all taken into account, 24 of the 28 groups of women show lower average heat-productions than they would if they were men of similar weight, stature, and age. The general averages for all the individuals of given stature-groups or weight-groups are by both methods without exception smaller than would be found in men of like physical dimensions. The average deficiency for the whole series of women is 94.0 calories per 24 hours when stature, weight, and age are taken into account, and 112.3 calories when stature and weight only are considered. The differences for the subgroups naturally vary widely because of the small numbers of individuals. The general average percentage deficiency when weight and stature only are considered in the calculations of the theoretical heat-productions is 7.3 per cent. When age is taken into account as well as stature and body-weight, the deficiency is 6.2 per cent.

TABLE 83.—*Differences in the metabolism of men and women. Test based on data of Palmer, Means, and Gamble.*

Subject.	Age.	Weight.	Height.	Total calories per 24 hours.	Calculated heat.	Actual less calculated.	Percentage difference.
Miss M. A. H.	21	57.9	157	1434	1506	− 72	4.8
Miss R. R.	24	70.9	169	1648	1725	− 77	4.5
Miss H.	22	48.1	155	1143	1355	−212	15.6
Miss D. L.	21	76.0	168	1497	1810	−313	17.3
Miss F. M. R.	20	77.7	166	1635	1830	−195	10.7
Miss L. F. W.	21	79.8	170	1480	1853	−373	20.1
Miss R. Rob.	23	67.5	170	1444	1690	−246	14.6

More conclusive proof of the existence of a sexual differentiation with respect to metabolism could hardly be expected.

As a further test of our method we may compute the daily heat-productions of the 7 young women studied by Palmer, Means, and Gamble [15] from the equation, based on our total men. The results appear in table 83. For every individual the actual heat-production is lower than it would have been in men of the same weight, stature, and age. The differences range from 72 to 373 calories per 24 hours.

[15] Palmer, Means, and Gamble, Journ. Biol. Chem., 1914, **19**, p. 239; Means, *ibid.*, 1915, **21**, p. 263.

In percentages of the theoretical heat-production they range from 4.5 to 20.1 lower than in men of the same weight, stature, and age. Thus this series of measurements by another group of observers, whether analyzed by the simple method of averages, as on page 204, or by the special methods here employed, fully confirms the conclusions drawn from our own data.

We must however in this connection refer to certain considerations to be taken up in the following chapter (p. 232).

A discussion of the data on the metabolism of German men and women recorded by Magnus-Levy and Falk is reserved for the following chapter (page 232).

TABLE 84.—*Deviations of metabolism of individual women from the masculine standard. (Note the high proportion of cases in which metabolism is lower.)*

Deviations from the male standard.	Prediction from age.	Prediction from body-surface.	Prediction from stature.	Prediction from body-weight.	Prediction from stature and weight.	Prediction from stature, weight, and age.
+338 to +412	..	..	1	..	..	..
+263 to +337	..	..	4	..	..	..
+188 to +262	1	3	1	..	2	1
+113 to +187	..	3	4	1	3	3
+ 38 to +112	4	9	7	8	9	9
− 37 to + 37	9	19	14	11	17	22
− 38 to −112	9	22	22	22	22	22
−113 to −187	5	20	20	18	21	25
−188 to −262	21	16	14	20	17	12
−263 to −337	18	6	10	12	7	6
−338 to −412	20	2	5	5	1	2
−413 to −487	10	2	1	2	2	1
−488 to −562	5	1	..	3	2	..
−563 to −637	1	..	..	..	..	..
−638 to −712	..	..	..	1	..	..

In the foregoing discussion comparisons have been made on the basis of differences in the empirical and theoretical average metabolism of individuals of various ages, statures, body-weights, body-surfaces, of various statures and body-weights, and of various statures, weights, and ages. As far as we know, these methods of comparison are free from all objections and give conclusive results. They fail, however, to give the distribution of the individual errors of predicting female from male metabolism due to the sexual differentiation which has been shown to exist.

These errors we have seriated in a grouping of 75 calories range in table 84. The entries in the first four frequency columns of this table show the distribution of the deviations of the actual heat-productions of our women from the values which would most probably be found if they were men of like age, stature, body-weight, or body-surface area

as measured by the Du Bois height-weight chart. The fifth column shows the deviations of the observed from the theoretical values when the latter are calculated by the simultaneous use of stature and body-weight. Finally, the last column shows the deviations of the observed from the theoretical values when body-weight, stature, and age are simultaneously taken into account.

Taking deviations of −37 to +37 as representing a central "zero" class, we note that by all methods there is a large excess of negative differences—*i.e.*, of differences indicating a lower metabolism in women. Thus, on the basis of computation involving age there are only 5 individuals showing a metabolism more than 37 calories per day above their theoretical heat-production as compared with 89 showing a metabolism of over 37 calories below their theoretical heat-production. When computation is based on body-surface area, only 15 women show more than 37 calories per day above their theoretical heat-production as compared with 69 who are in defect by the same amount or more. On the basis of stature the individuals of the two classes stand in the ratio of 17 to 72; on the basis of body-weight in the ratio of 9 to 83; on the basis of both weight and stature in the ratio of 14 to 72, and on the basis of weight, stature, and age in the ratio of 13 to 68. Thus the results for individuals fully substantiate the conclusions based on averages above.

4. COMPARISON OF BASAL METABOLISM OF MALE AND FEMALE NEW-BORN INFANTS.

The foregoing analysis of the data for adults has demonstrated beyond all question the differentiation of the adult male and female individual in man in respect to metabolic activity. From the standpoint of the student of the physiology of sex it is important to inquire whether this differentiation obtains only during the period of adult life or whether it is demonstrable in infancy. To test this matter, we naturally turn to Dr. Fritz B. Talbot's series of new-born infants.[16] The method to be followed is identical with that used above. We shall predict the metabolism of girl infants from constants based on the boys and determine the sign and the magnitude of the difference between the observed and calculated values. We require, therefore, equations showing the regression of total heat on stature (body-length), on weight, and on body-surface in the male infants. These are

$$h = 25.156 + 34.517\,w,\quad h = -229.576 + 7.340\,s,\quad h = -31.703 + 749.914\,a_L$$

where h = total heat per 24 hours, w = weight, s = stature (length), and a_L = body-surface area computed by the Lissauer formula.

The results for the infants grouped by body-length are shown under the caption "Prediction from linear equations" in table 85. In three

[16] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 233, 1915.

groups the average heat-productions predicted on the assumption that the subjects were boys of like body-length are higher and in three groups they are lower than the actual mean values. Thus, as far as this test goes, it furnishes no evidence of a sexual differentiation in metabolism in new-born infants.

TABLE 85.—*Tests for differences in metabolism of male and female infants.*

Female infants classified by stature.	Mean actual total heat.	Prediction from linear equations.			Prediction from planar equations.		
		Mean predicted total heat.	Actual less predicted.	Percentage of predicted.	Mean predicted total heat.	Actual less predicted.	Percentage of predicted.
46.0 to 47.0	111.3	112.0	−0.8	0.7	118.3	−7.0	5.9
47.5 to 48.5	120.1	121.1	−1.0	0.8	119.7	+0.4	0.4
49.0 to 50.0	139.7	134.6	+5.1	3.8	133.5	+6.2	4.7
50.5 to 51.5	142.0	145.3	−3.3	2.3	146.9	−4.9	3.3
52.0 to 53.0	161.1	155.7	+5.4	3.5	158.4	+2.7	1.7
53.5 to 54.5	168.0	167.8	+0.3	0.1	172.3	−4.3	2.5

The differences between the actual heat-production and the theoretical heat-production as calculated from the regression of total heat on body-surface in the boys are shown for groups of girl infants classified according to body-surface by the Lissauer formula in the first section of table 86. Those calculated from the equation for the relationship between total heat-production and body-weight in the boys appear in groups of various body-weights in the first part of table 87.

TABLE 86.—*Tests for differences in metabolism of male and female infants.*

Female infants classified by body-surface.	Mean actual total heat.	Prediction from linear equations.			Prediction from planar equations.		
		Mean predicted total heat.	Actual less predicted.	Percentage of predicted.	Mean predicted total heat.	Actual less predicted.	Percentage of predicted.
0.170 to 0.186	109.0	106.0	+3.0	2.8	106.0	+3.0	2.8
0.187 to 0.203	122.1	116.4	+5.7	4.9	115.3	+6.9	5.9
0.204 to 0.220	120.8	125.3	−4.5	3.6	124.3	−3.5	2.8
0.221 to 0.237	137.6	140.3	−2.7	1.9	138.4	−0.8	0.6
0.238 to 0.254	153.1	150.9	+2.3	1.5	150.6	+2.5	1.7
0.255 to 0.271	163.1	164.9	−1.7	1.0	164.9	−1.7	1.0
0.272 to 0.288	181.5	177.0	+4.5	2.5	178.0	+3.5	2.0

By both of these methods of computation and analysis, the results are very similar to those found in the grouping by stature above. Some of the groups show a lower, others a higher, metabolism than the computed value. Taking these data as a whole they afford no evidence that the sexual differentiation in metabolic activity demonstrated for the adults obtains in new-born infants.

Using the multiple-regression equation,

$$h=22.104+31.049w+1.162s,$$

for the boy babies, to predict the heat-productions of the girl babies

we have the deviations of the average actual from calculated heat-productions shown under the caption "Prediction from planar equations" in tables 85 to 87. These differences are sometimes positive and sometimes negative in sign. They show, therefore, that the actually observed heat-productions of the girl babies are sometimes higher and sometimes lower than they would be expected to be if they were boys of the same physical dimensions. As far as our data go they indicate, therefore, that on the average there is no sensible difference between the heat-productions of the two sexes in the first week of life.

TABLE 87.—*Tests for differences in metabolism of male and female infants.*

Female infants classified by body-weight.	Mean actual total heat.	Prediction from linear equations.			Prediction from planar equations.		
		Mean predicted total heat.	Actual less predicted.	Percentage of predicted.	Mean predicted total heat.	Actual less predicted.	Percentage of predicted.
2.12 to 2.46	109.0	107.0	+2.0	1.9	106.0	+3.0	2.8
2.47 to 2.81	123.6	117.1	+6.5	5.6	116.1	+7.5	6.5
2.82 to 3.16	118.9	125.1	−6.3	5.0	124.6	−5.7	4.6
3.17 to 3.51	137.6	139.7	−2.1	1.5	138.4	−0.8	0.6
3.52 to 3.86	153.1	150.5	+2.6	1.7	150.6	+2.5	1.7
3.87 to 4.21	163.1	164.9	−1.7	1.0	164.9	−1.7	1.0
4.22 to 4.56	181.5	178.0	+3.5	2.0	178.0	+3.5	2.0

5. RECAPITULATION.

Our analysis of the available data to ascertain whether men and women differ in the level of their metabolism has fully confirmed and considerably extended the conclusions reached by Benedict and Emmes in the first critical investigation of the problem. Our finding that the metabolism of women is significantly lower than that of men is based on three lines of evidence.

1. The general averages are higher in men than in women. The average woman shows a daily heat-production about 300 calories less than the average man. If correction be made for body-size by expressing heat-production in calories per kilogram of body-weight, she shows an average heat-production of about 1.2 calories per unit of weight less than the man. If body-surface area be used as the basis of correction, the woman shows daily heat-production of 77 calories per 24 hours per square meter as measured by the Meeh formula and 75 calories per square meter as measured by the Du Bois height-weight chart less than that of the man.

2. The deviation of heat-production of the individual woman from the general average associated with a deviation in her body-weight from the general average is less than comparable deviations in the man. When changes in heat-production associated with changes in other characters in men and women are compared by means of equations

based on the data as a whole, the line for the men is found to lie above that for the women.

3. When the theoretical heat-production of women is calculated by inserting their actual physical measurements in equations based on series of men, the actual heat-production is generally lower than the theoretical value. Larger women show a relatively larger deficiency in heat-production than smaller ones. The suggestion is made that body-weight is the primary factor in determining the greater deficiency in the heat-production of larger women, and that it is observable in the case of stature and body-surface area primarily because these are correlated with body-weight.

The most critical test shows that when body-weight, stature, and age are taken into account women show about 6.2 per cent lower metabolism than men.

Our results show that the differentiation of the sexes in metabolism is not evident in new-born infants. The researches of Sondén and Tigerstedt suggest that it is well marked in youth.

Our findings are not in accord with the conclusion of Sondén and Tigerstedt [17] "dass sich der im Kindes - und Jugendalter so deutlich und scharf hervortretende Unterschied zwischen den beiden Geschlechtern allmählich verwischt, um endlich bei herannahendem Greisenalter ganz zu verschwinden." Instead we find the difference between the metabolism of men and women well marked throughout the period of adult life.

[17] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, 6, p. 96.

CHAPTER VIII.

STANDARD BASAL METABOLISM CONSTANTS FOR PHYSIOLOGISTS AND CLINICIANS.

1. THE NECESSITY FOR AND FUNDAMENTAL NATURE OF STANDARD METABOLISM CONSTANTS.

While the discussions in the foregoing chapters should show that the determination of basal metabolism, or of variations in metabolism, in normal men and women presents a series of important physiological problems, it is quite evident that investigations of metabolism will receive the widest recognition and be of the greatest practical importance if they can be extended to include measurements based on individuals performing different amounts or kinds of work, subsisting on different diets, or suffering from various diseases.

All such studies must be comparative. The metabolism of a group of individuals affected by any special condition has little interest unless it can be shown to be the same as or to differ sensibly from the basal metabolism of a comparable group of normal individuals. For example, before any discussion of metabolism in individuals suffering from disease can be of value a series of non-pathological controls must be established to serve as a basis of comparison. The need for such control constants has been recognized with varying degrees of clearness by all those who have worked on the problem of the metabolism of individuals suffering from disease.[1]

While, as far as we are aware, it is now universally considered that the value of a metabolism determination on a pathological subject is strictly limited by the trustworthiness of the normal control with which it is compared, the establishment of suitable controls has been the subject of serious disagreement. "Controversies have raged more

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[1] Magnus-Levy and Falk (Arch. f. Anat. u. Phys., Physiol. Abt., 1899, Suppl., p. 315) stated one of the purposes of their research begun in 1895 to have been the determination of normal metabolism data for comparison with their pathological records. Benedict and Joslin (Carnegie Inst. Wash. Pub. No. 136, 1910) in 1910 published such determinations on normal subjects as were then available as a basis of comparison with their diabetic individuals. Lusk (Science, n. s. 1911, **33**, p. 433) in reviewing this publication, emphasizes indirectly the importance and the inadequacy of control series.

Again, in reference to investigations of respiratory metabolism in disease, Du Bois (Am. Journ. Med. Sci., 1916, **151**, p. 785: also Studies Dept. Physiol., Cornell Univ. Med. Bull., 1917, **6**, No. 3, Part II) says: "The main object of all investigators has been to determine the heat-production of the patient while at complete rest 14 hours or more after the last meal. This is the so-called basal metabolism, and is of interest only when compared with the figures obtained on normal individuals. Since it is impossible to measure the metabolism of many of our patients when they are entirely recovered, it is necessary to calculate what the man's metabolism would be were he normal."

fiercely about the normal controls than about the pathological cases." [2] The difficulty has been twofold. First, the measurement of an adequately large series of individuals has been a very heavy undertaking. Second, the selection of the proper measure of metabolism in the control series has presented theoretical difficulties. In relation to the first of these we may quote a statement made as late as 1914: [3]

"The impetus given to the study of gaseous and gross metabolism during the past decade has resulted in a large number of observations, both in the domain of physiology and pathology. Investigators in pathology are, however, continually confronted by the paucity of normal data with which to compare their observations."

Somewhat later Gephart and Du Bois [4] wrote:

"The importance of the normal control has been emphasized so strongly by the serologists and the management of the control has been developed by them to such an art that it has seemed advisable to apply some of their methods of critique to the study of the respiratory metabolism. . . . . These precautions . . . . have been made necessary by the fact that the normal control is usually the point of attack in serological controversies. Likewise in the study of metabolism the normal control is coming to be recognized as the weakest part of the experiment. . . . . The literature is notoriously filled with false theories, of which by far the greater part would never have been promulgated if sufficient attention had been given to normal controls."

Notwithstanding the confidence which has generally prevailed in the validity of the expression of metabolism in calories per square meter of body-surface area, the theoretical difficulties in the selection of control series have not passed unrecognized. "The selection of the proper normal base-line is a matter of extreme difficulty." [5] The detailed discussion in the preceding chapters of the factors associated with variations in basal metabolism suggests that the difficulties of the selection of proper controls has been underestimated rather than overestimated in the past.

A brief consideration of the fundamental principles of the establishment of standard or control constants to be used as a basis of comparison in experimental work is in order.

In the simplest cases the metabolism of an individual under any exceptional condition may be compared with his own basal metabolism which serves, therefore, as a standard or control. This is true, for example, in the case of variations in muscular activity, in rationing or in prolonged fasting. Even in the case of protracted illness, suggestion has been made of the possibility of using basal metabolism determinations upon the same individual, obtained subsequent to recovery, as a basis of comparison with the constants secured when the subject

[2] Du Bois, Am. Journ. Med. Sci., 1916, **151**, p. 785.
[3] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139.
[4] Gephart and Du Bois, Arch. Intern. Med., 1915, **15**, p. 835.
[5] Gephart and Du Bois, Arch. Intern. Med., 1915, **15**, p. 858.

was in the pathological state. Such a course is, however, obviously impracticable in the vast majority of instances, since the duties or inclinations of the former patient may preclude periods of study subsequent to those made during confinement in a hospital. Furthermore, subsequent to a period of severe illness, there is no assurance in any *single* period of determinations that the subject has returned, or indeed that he ever will return, to the normal condition, or at least to the condition antecedent to the disease. Finally, because of the great variations in basal metabolism from individual to individual, or under experimentally controllable conditions within the same individual, *single* comparisons have little crucial value as a basis for generalization concerning the influence of special conditions on metabolism unless the influence be very great.

Practically, therefore, one is reduced in the great majority of cases, and especially in those of the greatest medical interest, to the statistical method of comparing observations on a group of individuals of a special class (the metabolism of which is being investigated) with those on individuals which do not possess the characteristics under consideration, or with "normal" individuals.

In experimental work there are two ways in which control constants may be determined: (1) The control observations may be made simultaneously with those on the individuals of the special class under investigation. This method is necessarily followed when it is impossible to regulate external conditions with exactness and when individuals which are exactly comparable except for the particular characteristics under investigation must be employed—for example, in cases in which two mammals from the same litter, two groups of birds from the same clutch, or two lots of seedlings from the same parent plant must be utilized. (2) Standard determinations may be used as a basis of comparison for all special groups. This method may be followed in cases in which it is impossible to obtain for simultaneous observation individuals which are more nearly alike than those which can be obtained at other times, and in which the experimental technique is so highly perfected that there is no question but that measurements made at different times or by different observers are comparable within the limits of a very slight *physical* experimental error.

In work on metabolism the second method is not merely justified but necessary. The *justification* for the establishment of a standard control series instead of making normal control measurements for each pathological case lies in the fact that respiration chambers, calorimeters and other apparatus and technique essential for investigating basal metabolism have been brought to such a stage of perfection that, with proper chemical and physical standardizations at frequent intervals, technical errors may be disregarded. Furthermore, subjects upon whom basal metabolism determinations are made must comply so

exactly with a generally adopted set of conditions that there is no advantage in carrying out a normal control determination coincidentally with the measurement of the metabolism of subjects suffering from any disease which may be under investigation.

The *necessity* for establishing a standard control series rests upon two fundamental considerations. First, variation in basal metabolism from subject to subject is so great that to be of critical value a control series must comprise a relatively large number of individuals. Secondly, the very limited equipment available in all the scientific institutions of the world for carrying out trustworthy metabolism determinations and the great expenditure in time and effort necessary for making these determinations render it practically essential that data which may be regarded as standard for long periods of time be secured once for all, in order (in so far as possible) to set the limited equipment free for investigating the many pressing problems of metabolism under special conditions of exercise, nutrition, and disease. Hitherto control values have been established in two ways.

First, the *average* value of metabolism per unit of body-weight or body-surface in a selected group of subjects has been used as a control value, and the observed metabolism of the hospital patient or other subject, expressed in terms of the same units, has been compared directly with this value. This is the method used by the majority of investigators in the past.

Second, the average of the constants secured from a group of normal individuals as nearly as possible comparable, in physical characters, with the subjects of the special group under consideration is used as a standard of comparison. This is the selected-group method employed at the Nutrition Laboratory in a study of diabetes, of vegetarians and non-vegetarians, of athletes and non-athletes, and of men and women.

The obvious objection to the population-average method of computing control values is that, in obtaining the fundamental constant, individuals of the most diverse physical characters are lumped together indiscriminately. From the physiological standpoint it is quite unreasonable to compare a standard value obtained from a large number of normal robust individuals with that derived from an emaciated patient in the clinic; this is evidenced by the fact that an individual undergoing a prolonged fast may show a decrease of 28 per cent in his metabolism, as measured in relation to body-surface, simultaneously with the assumption of an emaciated condition quite comparable with that observed in some pathological subjects.

The selected-group method in which pathological or other special groups are compared with normal individuals of like height and weight, *i.e.*, of general anatomical and morphological similarity, is free from this very serious criticism, but is open to two others. (1) There is considerable opportunity for personal equation in the selection of the

series of individuals to be used as a control in any specific instance; (2) because of the well-known and large variations in the metabolism constant from subject to subject the average value based on a small group of individuals may be either too large or too small by an amount determined by the probable errors of random sampling.

It seems clear that some form of the selected-group method will furnish the most satisfactory basis of comparison. Ideally one should find a method which will combine all the advantages, and reduce to a minimum all of the disadvantages, of the two methods hitherto employed.

The results of the analysis in the preceding chapters have shown that four factors need to be taken into account in estimating the basal metabolism of a subject: sex, body-weight, stature, and age.

The importance of body-weight in the selection of controls has been very generally recognized, at least tacitly, by all those who have expressed metabolism in terms of oxygen consumption, carbon-dioxide excretion, or calories produced per kilogram of body-weight. While the relation of stature to metabolism is not so obvious as that of body-weight, it has been shown in Chapter IV to be a character of independent significance in the determination of metabolism. It has long been known that metabolism is related to age. In Chapter V this relationship has been expressed quantitatively.

The method used here for the establishment of standard normal metabolism constants is essentially an extension of the selected-group method used earlier for various comparisons at the Nutrition Laboratory. Instead of using the empirical average heat-production of an actually observed group of individuals, we shall give the "smoothed" or "graduated" values for groups of given age, stature, and body-weight as determined from equations based on all the available data. We thus obviate, as far as possible, the two main objections to the selected-group method: (*a*) the possibility of the influence of personal equation in the selection of the normal values to be used as controls in any specific case, and (*b*) the probable errors of random sampling attached to the control constants. The rather detailed application of the method in Chapters V, VI, and VII should have made the whole theory perfectly clear. There remains, therefore, merely the restatement of the equations and the tabling of a series of standard constants to be derived from them in the form most convenient for practical use.

As shown in Chapter VI, p. 190, the multiple prediction equations based on the total adults of the two sexes are

For men.............. $h = +\ 66.4730 + 13.7516\,w + 5.0033\,s - 6.7550\,a$
For women........... $h = +655.0955 + \ 9.5634\,w + 1.8496\,s - 4.6756\,a$

where h = total heat-production per 24 hours, w = weight in kilograms, s = stature in centimeters, and a = age in years. The evaluation of these equations, which are used in the calculation of the theoretical

heat-production for any individual, requires merely the substitution of the actually measured weight, stature, and age. The tabling of these equations for a range of body-weight, stature, and age which will be encountered in practice results in a multiple-prediction normal standard, or an adult standard normal, with which the observed basal metabolism (daily heat-production) of individual subjects may be compared. While the standard values are so arranged as to facilitate the comparison of individual subjects the reader must remember that because of the great variability of metabolism from subject to subject a comparison of a single subject of any special class furnishes a very slender basis for generalization concerning that class. It is only when reasonably consistent results are obtained from series of individual comparisons that generalizations can satisfactorily be drawn.

The validity of these formulas has been exhaustively tested in comparison with the methods hitherto employed in calorimetry in the section devoted to the body-surface law. It has there been shown that, when applied to the individual subjects of the largest series of basal metabolism data yet secured by a single group of observers, these formulas give the most satisfactory prediction of the basal metabolism of an unknown subject of any method hitherto employed. With certain reservations concerning the range of age over which these formulas may be legitimately applied, we have the highest confidence in their validity.

2. TABLES OF MULTIPLE PREDICTION STANDARD METABOLISM CONSTANTS.

For the convenience of those who have to estimate the metabolism of subjects from physical characteristics either in the clinical ward or in the physiological laboratory, we have prepared tables of the values of these equations for the various grades of body-weight, stature, and age. The form adopted for these tables has been determined by purely practical considerations. Because of the large number of permutations of weight, stature, and age, it is obviously out of the question to publish constants for each possible combination of these characters; but two tables of constants may be constructed from which the worker may obtain the most probable metabolism of a man (*i.e.*, the average metabolism of a group of individuals of like weight, stature, and age) by simply adding together the entry for body-weight in table I and that for stature and age in table II. For women the comparable entries in tables III and IV will be used.

These tables have been constructed to be entered by body-weight recorded to the nearest tenth of a kilogram, stature recorded to the nearest centimeter, and age to the nearest year. In following this course we have been under no illusions concerning these physical measurements, but have used the units which have become conventional among physiologists. A measurement of stature to the nearest centi-

meter is about the limit of accuracy. To retain tenths of kilograms is certainly weighing with a degree of refinement hardly justified by the continually changing state of the experimental object. Finally, when individuals are recorded to the nearest year of age we may remember that they are on an average a quarter of a year older or younger than the age to which they are assigned.

Against these objections is to be urged the fact that measurements which are not made with great refinement are very apt to lack essential accuracy. Since these are the divisions of the scales which have been most generally employed by physiologists it has certainly not seemed desirable to replace them by coarser ones. Furthermore, it must be noted that our equations are not based upon a few observations, but upon over 100 determinations for each sex. Therefore, as a basis of generalization, they have a much higher degree of accuracy than any single observation or group of a small number of observations.

The sources of error in using the multiple prediction tables are two.

(1) The tables themselves are based upon a finite number of observations. In comparison with physiological measurements as a class, the number of measurements is very large; biometrically considered it is small. Every constant in these equations is therefore, somewhat too large or somewhat too small because of the innate variability of human individuals. If another group of subjects were added to the series upon which these tables are based the factors would be *slightly* changed. The constants are subject to revision with increasing intensiveness or extensiveness of work, just as all physical and chemical constants are.[6] Until more data are available they must be taken as they are, with the understanding that the standard has its probable error, just as have the individual metabolism measurements which will be compared with it.

(2) As we have repeatedly emphasized in the foregoing pages, every individual metabolism measurement considered as a basis for generalization concerning the peculiarities of the individual upon which it is based (*e.g.* physical characteristics, pathological state, etc.) has a large probable error. Thus one can not compare the metabolism of a single individual of any specified type with the standard constant and use it as a basis of generalization. It is only when a series of individuals of the specified type are considered that generalizations may be drawn.

From the standpoint of arithmetical technique, the tables probably correctly represent the results of the largest series of determinations on normal men and women with an error of not over 1 calorie per 24 hours.[7]

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[6] We plan later to prepare a revised edition of these tables based upon more extensive data.

[7] The results could have been given in such a form that the final constants would have been arithmetically correct to less than a single calorie per 24 hours had decimal places been retained in the tables. This seemed a quite needless refinement. Those who desire may derive the theoretical values to more places directly from the equations. The theoretical values in the series of illustrations in this chapter were determined in this way.

In constructing these tables the constant term of the equation and the corrective term for body-weight are combined in table I for men and table III for women. The corrective term for stature and age is given in table II for men and table IV for women. *These tables must be used in conjunction only.* Thus table I or III must not be used to estimate the metabolism of an individual whose weight only is known. Tables II or IV must not be used to estimate the metabolism of an individual whose weight is unknown.

The use of the tables presents no difficulty whatever. Three examples follow:

Man 27 years old, 172 cm. in height, 77.2 kilos. weight.		Woman 22 years old, 166 cm. in height, 77.2 kilos. weight.		Woman 66 years old, 162 cm. in height, 62.3 kilos. weight.	
From table I	1128	From table III	1393	From table III	1251
From table II	678	From table IV	204	From table IV	− 9
Predicted calories	1806	Predicted calories	1597	Predicted calories	1242

3. ILLUSTRATIONS OF PRACTICAL APPLICABILITY OF STANDARD MULTIPLE PREDICTION TABLES OF BASAL METABOLISM.

In a foregoing chapter (VII) the practical usefulness of the equations upon which these tables are based has been fully demonstrated in their application to a specific problem, that of the sexual differentiation in metabolic activity. It now remains to supply further illustrations of their range of usefulness by applying them to certain cases in which the individuals were measured by workers outside of the Nutrition Laboratory, in which the individuals fall outside the range of age or of physical form upon which the equations were based, or in which the subjects were in a particular physiological or pathological state, the influence of which upon metabolism is under investigation.

Illustration A. Tests of Normality of Series of Determinations.

In applied calorimetry the need to be met is practically always the same. One requires to know whether a special series of metabolism measurements agrees with a larger series of determinations taken as a standard. If the special series is made up of individuals characterized by some specific condition, *e.g.*, rationing, exercise, or disease, the result of the comparison shows whether this specific peculiarity may or may not be considered to have a determining influence on the basal metabolism. Some special cases of this sort will be examined.

As a first illustration of the practical usefulness of our multiple-prediction equations, we may consider the agreement between certain series of measurements by other observers and the standard which has been based upon the Nutrition Laboratory experience. Take first a series of young men and women studied by Palmer, Means, and Gamble [8] and discussed in relation to the problem of the body-surface

[8] Palmer, Means, and Gamble, Journ. Biol. Chem., 1914, 19, p. 239.

law by Means.[9] The data for the application of the equations and the results of their application are shown in table 88 for the 8 men and in table 89 for the 7 women.

In these and the following comparisons the differences are taken

(actual metabolism) *less* (calculated metabolism)

so that a positive sign indicates supernormal and a negative sign subnormal metabolism in a subject. In this regard the constants of this chapter differ from those in Chapter VI. The reason for the difference seems a logical one. In that place we were seeking to determine empirically which of a series of methods proposed for predicting metabolism actually gives the closest approximation to the true value in a large series of subjects. We therefore determined which predicted with the smallest error, *i.e.*, which gave the lowest value of

TABLE 88.—*Comparison of metabolism of men studied by Palmer, Means, and Gamble with normal (multiple prediction) standard.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Dr. W. W. P.	32	93.9	187	2004	2077	− 73	− 3.5
Mr. H. L. H.	27	62.0	172	1574	1597	− 23	− 1.4
Dr. W. S. W.	25	73.8	177	1660	1798	−138	− 7.7
Dr. L. W. H.	25	68.4	169	1671	1684	− 13	− 0.8
Dr. P. H. P.	27	77.2	172	1620	1806	−186	−10.3
Dr. J. H. M.	29	70.7	175	1599	1718	−119	− 6.9
Dr. J. L. G.	30	68.1	181	1679	1706	− 27	− 1.6
Dr. L. H. N.	31	58.1	169	1452	1502	− 50	− 3.3

TABLE 89.—*Comparison of metabolism of women studied by Palmer, Means, and Gamble with normal (multiple prediction) standard.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Miss M. A. H.	21	57.9	157	1434	1401	+ 33	+ 2.4
Miss R. R.	24	70.9	169	1648	1534	+114	+ 7.4
Miss H.	22	48.1	155	1143	1299	−156	−12.0
Miss D. L.	21	76.0	168	1497	1594	− 97	− 6.1
Miss F. M. R.	20	77.7	166	1635	1612	+ 23	+ 1.4
Miss L. F. W.	21	79.8	170	1480	1634	−154	− 9.4
Miss R. Rob.	23	67.5	170	1444	1508	− 64	− 4.2

(calculated metabolism) *less* (actual metabolism).

But having established the best method and utilized the largest available series of data uniformally obtained as the basis of our constants, we feel fully justified in taking these equations as our standard, and in considering that smaller series either do or do not agree with this

[9] Means, Journ. Biol. Chem., 1915, **21**, p. 263.

standard, as the actual constants may indicate. The differences are therefore taken

(actual metabolism) *less* (calculated metabolism)

to give the proper sign to the difference.

Without exception the 8 men are subnormal in their daily heat-production. The differences range from 13 to 186 calories and are on an average 78.6 calories. Expressed as a percentage of the calculated heat-production, the differences range from 0.8 to 10.3 with a general average of 4.4 per cent.

In the case of the women, in which the theoretical heat-production is calculated by inserting the values for weight, stature, and age of the individual under consideration in our equation based on 103 women, the deviation of the actual from the theoretical values is not so great. In 3 cases metabolism is higher and in 4 cases lower than would be expected. The average difference is $(+170-471)/7=-43.0$ calories. Thus while the young women are more nearly typical than the young men studied by Palmer, Means, and Gamble, their individuals of both sexes show a tendency to a defective metabolism rate.

We have no suggestion to offer concerning the technical or physiological explanation of the apparent tendency of this series to subnormal metabolism. The suggestion may of course be offered that it is our standards which are at fault. There are various evidences that this is not the case. First of all, the observations upon which our standards are based have been made by a carefully standardized technique but by a number of observers. Thus the probability of an influence of personal equation is to a considerable extent reduced. The large number and great diversity of individuals dealt with furnishes a strong guarantee for the validity of the constants. Furthermore the application of our method to other series of data indicates supernormal metabolism in comparison with our standards. Thus we have abstracted from the classical paper of Magnus-Levy and Falk [10] the ages, weights, and statures of a number of men and women and have calculated the total calories per 24 hours from their measurements of the respiratory exchange. The essential values are given in table 90. Of the 10 men 7 show a heat-production above standard as compared with 3 which show heat-production below standard. The deficiencies range from -13 to -61 calories, whereas the excesses range from $+6$ to $+203$ calories. With one exception the 14 women show a daily heat-production above normal. The excess ranges from 22 to 359 calories per 24 hours or from 1.6 to 25.7 per cent.

The average excess for the 10 men is 54.5 calories, while for the 14 women it is 110.2 calories per 24 hours. The average percentage deviation from standard without regard to sign is 5.3 for men and 8.5

[10] Magnus-Levy and Falk, Arch. f. Anat. u. Physiol., Physiol. Abt., Suppl. 1899, pp. 314–381. Tables I and III.

for women. Regarding signs, the men show an excess of 3.7 per cent and the women an excess of 8.5 per cent.

Thus the adult series of Magnus-Levy and Falk show supernormal metabolism when compared with the standard which we have adopted, whereas the subjects examined by Palmer, Means, and Gamble show a subnormal metabolism. If, as judged by the Palmer, Means, and Gamble series, our standards predict a metabolism somewhat too high, when judged by the Magnus-Levy and Falk series they predict a basal metabolism somewhat too low. Our standards can not be changed without making the results of one or the other of these groups of observers appear much more abnormal than they now seem.

TABLE 90.—*Metabolism of the German men and women studied by Magnus-Levy and Falk compared with American normal (multiple prediction) standard.*

Name and number.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Men.							
1. Rud	24	43.2	148(±)	1333	1239	+ 94	+ 7.6
2. L	30	50.8	153	1315	1328	− 13	− 1.0
3. Rutt	26	53.0	153	1527	1385	+142	+10.3
4. W	56	56.5	170(±)	1519	1316	+203	+13.4
5. B	32	58.0	161	1510	1453	+ 57	+ 3.9
6. Prof. Z	43	65.0	161(±)	1498	1475	+ 23	+ 1.6
7. Dr. M.-L.	25	67.5	167	1608	1661	− 53	− 3.2
8. Dr. L.-Z.	22	67.5	167	1621	1682	− 61	− 3.6
9. Sp	29	82.7	175	2030(?)	1883	+147	+ 7.8
10. Schm	22	88.3	176	2019(?)	2013	+ 6	+ 0.3
Women.							
1. B. K	40	31.0	135	1073	1014	+ 59	+ 5.8
2. G. D	38	32.2	133	1109	1031	+ 78	+ 7.6
3. W. Spr	35	37.9	142	1204	1117	+ 87	+ 7.8
4. O. K	25	39.0	139	1344	1168	+176	+15.1
5. L. Gr	21	47.2	147	1345	1280	+ 65	+ 5.1
7. M.W	20	49.4	159	1355	1328	+ 27	+ 2.0
8. H. M	28	51.2	157	1466	1304	+162	+12.4
9. H. Sch	18	54.0	152	1529	1368	+161	+11.8
10. M. Kl	17	54.0	156	1403	1381	+ 22	+ 1.6
11. E. Spl	28	61.3	156	1758	1399	+359	+25.7
12. L. W	20	61.0	167	1508	1454	+ 54	+ 3.7
13. Schw. M	26	62.7	155(?)	1602	1420	+182	+12.8
14. A. Sche	22	68.2	159	1612	1499	+113	+ 7.5
15. Br. K	27	76.5	169	1571	1573	− 2	− 0.1

Possibly such tendencies to subnormal or supernormal metabolism as those seen in the two groups of men and women just studied may be due merely to errors of random sampling in the selection of the subjects. This seems, however, highly improbable. To another possible explanation we shall return in a moment. That such tendencies are not necessarily characteristic of subseries is evident from the following further illustration.

Table 91 contains the physical data and the actual and computed heat-production of a number of men studied at the Nutrition Labora-

tory after the tables for the present volume were closed.[11] For permission to use the constants of these men in advance of their publication elsewhere we are indebted to our associates Dr. T. M. Carpenter, Mr. L. E. Emmes, Miss M. F. Hendry, and Dr. P. Roth. In 13 cases these subjects showed a basal metabolism of from 24 to 328 calories less than would have been expected from their stature, weight, and age, whereas in 18 cases they were characterized by a basal metab-

TABLE 91.—*Comparison of metabolism of series of men recently investigated by Carpenter, Emmes, Hendry, and Roth, with normal (multiple prediction) standard based on earlier series.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
W. G. S.	19	63.5	171	1704	1667	+ 37	+ 2.2
E. R. K.	20	69.0	168	1812	1721	+ 91	+ 5.3
A. S. P.	21	69.3	169	1733	1723	+ 10	+ 0.6
J. L. G.*	21	65.5	163	1600	1641	− 41	− 2.5
G. C. G	22	71.3	171	1874	1754	+120	+ 6.8
R. T. V.	22	65.8	175	1610	1698	− 88	− 5.2
H. H. H.	22	71.5	173	1793	1767	+ 26	+ 1.5
J. F. T.	22	63.8	188	1750	1736	+ 14	+ 0.8
P. G. H	22	52.1	176	1549	1515	+ 34	+ 2.2
R. K. B.	22	65.8	179	1694	1718	− 24	− 1.4
C. A. C.	22	64.9	180	1656	1711	− 55	− 3.2
A. C. B.	22	77.6	175	1533	1861	−328	−17.6
H. A. M.	23	63.5	174	1702	1655	+ 47	+ 2.8
S. N. G.	23	60.8	178	1827	1638	+189	+11.5
W. J. S.	23	56.5	172	1330	1549	−219	−14.1
H. O.	23	67.2	172	1628	1696	− 68	− 4.0
C. F. M.	23	51.1	161	1258	1419	−161	−11.3
O. A. G.	24	66.8	166	1788	1653	+135	+ 8.2
T. H. N.	24	69.1	190	1868	1805	+ 63	+ 3.5
A. G. N	24	59.9	172	1600	1589	+ 11	+ 0.7
F. S.	24	57.4	172	1515	1554	− 39	− 2.5
W. F. M.	24	76.1	181	1863	1857	+ 6	+ 0.3
C. S. B.	24	61.4	174	1632	1619	+ 13	+ 0.8
L. J. T.	25	59.5	176	1471	1596	−125	− 7.8
L. F. F.	25	57.5	167	1606	1524	+ 82	+ 5.4
J. A. C.	25	59.6	177	1663	1603	+ 60	+ 3.7
H. B.	25	64.6	166	1482	1617	−135	− 8.3
G. A. B.	26	61.8	167	1493	1576	− 83	− 5.3
K. B. C	26	79.8	177	1759	1874	−115	− 6.1
K. G. M.	32	68.8	171	1889	1652	+237	+14.3
R. W. P.	44	64.3	170	1572	1504	+ 68	+ 4.5

* J. L. G., aged 20 years and 6 months is considered 21.

olism from 6 to 237 calories higher than the theoretical value. Had the sample been exactly typical of the standard control series the ratio should have been 15.5 : 15.5 instead of 18 : 13. Thus there is a deviation of only $13-15.5=2.5\pm1.9$ from the equality which should result if prediction could be made without a bias toward too high or too low values.

[11] These subjects will be included with such others as may become available in any subsequent revision of our prediction tables.

The most widely divergent individuals are A. C. B. with a metabolism which is subnormal by 17.6 per cent and K. G. M. with a metabolism which is supernormal by 14.3 per cent. Of the remaining 29 men only 3 deviate more than 10 per cent from the standard.

Taking the series as a whole, the average observed heat-production is 1653.35 calories whereas the average calculated heat-production is 1661.03 calories. Thus for 31 individuals the average error of our multiple prediction formula is only +7.68 calories per day. This is only +0.46 per cent of the predicted value. If the individual differences between the predicted and the measured daily heat-productions of these men be considered without reference to their sign, *i.e.*, without regard to the fact that some are subnormal while others are supernormal, we find that there is an average difference of ±87.87 calories. Thus by the use of our equations we have been able to predict the heat-production of 31 subjects with an average (±) error of 5.30 per cent. This series may therefore be regarded as quite typical of the standard, and might in consequence be legitimately employed for any rationing or other metabolism experiment.

Returning to the discrepancy between the series of measurements by Magnus-Levy and Falk and our standard basal constants, we may note that in addition to the two possible explanations suggested above —*i.e.*, faulty technique and errors of random sampling in the selection of the subjects—another must be considered. It is quite possible that the German and American populations from which these subjects were drawn are differentiated with respect to the magnitude of their metabolism. Some further light may be thrown upon this question by computing the metabolism of the German girls, women, and old women from the equation based on the 136 American men. In doing this we are determining what the heat-productions of these individuals should be if they were American men of like stature, weight, and age. As fully discussed in Chapter VII, comparison of the actual with the theoretical heat-productions will then show whether German women show a higher or a lower metabolism rate than American men. The results are set forth in table 92.

Leaving the girls out of consideration for the moment we note that of the 17 women from 17 to 86 years of age *all but 5 show a daily heat-production in excess of that computed on male standards.* The deficiencies range from −39 to −211 calories with an average of −94.2 calories, whereas the excesses range from +36 to +369 calories with an average of 152.0 calories. For all the women the average daily excess is (1824−471)/17 = 79.6 calories.

Expressing these differences in relative terms, we note that the German women range from 11.8 per cent below to 39.3 per cent above the standard male values. The average for the 5 women who fall below the masculine standard is 5.8 per cent, while the average for the

12 women who have a metabolism above this standard is 14.0 per cent. For the whole series, regarding signs, the average excess is 8.2 per cent.

Now data are not as yet available for determining the real significance of these actually demonstrated differences. They may be due to defective technique, although we believe that other students of human metabolism will agree with us in holding the manipulative features of Magnus-Levy's work in the highest regard. They may represent real physiological differentiation, possibly due to differences in plane of nutrition [12] or in muscular training (to be discussed under

TABLE 92.—*Comparison of metabolism of German girls and women studied by Magnus-Levy and Falk with the American masculine normal (multiple prediction) standard.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Girls.							
1. A. K...	7	15.3	107	866	765	+101	+13.2
3. A. M...	12	24.0	129	962	961	+ 1	+ 0.1
4. Fr. W..	12	25.2	128	938	972	− 34	− 3.5
5. E. Gl...	13	31.0	138	1217	1095	+122	+11.1
6. H. Sch..	11	35.0	141	1313	1179	+134	+11.4
7. Fr. Th..	14	35.5	143	1299	1176	+123	+10.5
9. M. P...	11	42.0	149	1459	1315	+144	+11.0
Women.							
1. B. K...	40	31.0	135	1073	898	+175	+19.5
2. Gd.....	38	32.2	133	1109	918	+191	+20.8
3. W. Spr.	35	37.9	142	1204	1062	+142	+13.4
4. O. K...	25	39.0	139	1344	1129	+215	+19.0
5. L. Gr...	21	47.2	147	1345	1309	+ 36	+ 2.8
7. M. W...	20	49.4	159	1355	1406	− 51	− 3.6
8. H. M...	28	51.2	157	1466	1367	+ 99	+ 7.2
9. H. Sch..	18	54.0	152	1529	1448	+ 81	+ 5.6
10. M. Kl..	17	54.0	156	1403	1475	− 72	− 4.9
11. E. Spl..	28	61.3	156	1758	1501	+257	+17.1
12. L. W...	20	61.0	167	1508	1606	− 98	− 6.1
13. Schw. M	26	62.7	155(?)	1602	1529	+ 73	+ 4.8
14. A. Sche.	22	68.2	159	1612	1651	− 39	− 2.4
15. Br. K...	27	76.5	169	1571	1782	−211	−11.8
Old women.							
4. Kl.....	71	49.5	145	1088	993	+ 95	+ 9.6
5. Schm...	83	51.0	146	1307	938	+369	+39.3
7. Schä....	86	59.3	150	1143	1052	+ 91	+ 8.7

Illustration D, below) in the women of the German and the men of the American classes from which the subjects were drawn. The solution of this question must be a problem for the future. The results show with the greatest clearness the value of standard tables based upon three characters for the direction of future research.

Again the results exemplify the importance of large groups as a basis for conclusions. Five of the 17 women show heat-productions less than the male standard. Had a smaller number been examined, one or more of these might have been included and the result have been far less conclusive than it seems with 17 determinations.

[12] See Chapter VI, p. 196.

ILLUSTRATION B. METABOLISM IN CHILDHOOD AND YOUTH AND IN EXTREME OLD AGE.

In Chapter V we discussed in detail the changes in metabolism which occur with increasing age during the period of adult life. As we indicated there, the limits which mark off the stages of development from the period of maturity and the period of old age from that of extreme old age are very indefinite, or at least are determinable only with difficulty.

Our equations do not fully represent the metabolism of the developmental period. Neither do the observations upon which they are based contain numbers of very old men or women adequately large to justify using them as a standard for determining the influence of special conditions (*e.g.* the incidence of a specific disease) upon the metabolism of advanced old age. For these very reasons our equations are particularly adapted to determining whether the metabolism of individuals in these extremes of the life-cycle differs from that characteristic of the wide central range of mature life. In applying them to this problem we calculate the metabolism of the individuals of extreme age on the assumption that it is given by inserting the weight, stature, and age of the subjects in the equations based on our adult series. Comparison of the values obtained by actual measurement with that given by the equations then shows whether the metabolism of the age in question differs from that in adult life.

TABLE 93.—*Comparison of metabolism of Du Bois boy scouts with the adult masculine normal (multiple prediction) standard.*

Name.	Age.	Weight in kilograms.	Height in centimeters.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
J. D. D. B.	12	34.5	153	1340	1225	+115	+ 9.4
Leslie B.	13	28.5	141	1300	1076	+224	+20.8
Raymond M.	13	30.4	141	1415	1102	+313	+28.4
Reginald F.	13	35.4	148	1485	1206	+279	+23.1
F. R. S.	13	32.1	142	1375	1131	+244	+21.6
Arthur A.	14	30.6	147	1348	1128	+220	+19.5
Harry B.	14	36.6	146	1401	1206	+195	+16.3
Henry K.	14	36.0	148	1432	1207	+225	+18.6

Consider first the boy scouts studied by Du Bois.[13] The essential details are given in table 93. The computed values are in all cases lower than the observed. The differences range from 115 to 313 calories per 24 hours, with an average of 227 calories. Thus boys of 12 or 14 years of age have a basal metabolism from 115 to 313 calories per day higher than would be expected if they were adult individuals of the same weight and height. Expressing these results in terms of percentages of the adult standard, as must be done in comparing boys with men, we note that the boys have a metabolism from 9.4 to 28.4

[13] Du Bois, Arch. Intern. Med., 1916, **17**, p. 887.

per cent higher than they would be expected to have if they were adults of the same height and weight. The average superiority of the boys is 19.7 per cent of the standard. Thus if the boys were able to remain in complete muscular repose during the experimental periods, and if the light breakfast had no measureable influence on their metabolism, so that the constants may be looked upon as truly basal, it is evident that the metabolism is relatively high at the onset of puberty, and that the decrease from this period to that of maturity is more rapid than during adult life.

TABLE 94.—*Comparison of metabolism of German boys and girls studied by Magnus-Levy and Falk with American normal (multiple prediction) adult standards.*

Name and number.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Boys.							
2. M. N...	6	14.5	110	926	776	+150	+19.3
3. Fr. H...	6	18.4	110	970	829	+141	+17.0
4. G. H...	7	19.2	112	1067	844	+223	+26.4
5. K. W...	7	20.8	110	1153	856	+297	+34.7
6. E. J....	9	21.8	115	1036	881	+155	+17.6
7. P. Oe...	11	26.5	129	1151	1002	+149	+14.9
8. A. T....	10	30.6	131	1338	1075	+263	+24.6
9. O. Gr...	14	36.1	142	1310	1179	+131	+11.1
10. E. K...	14	36.8	142	1285	1188	+ 97	+ 8.2
11. K. Ke..	16	39.3	149	1352	1244	+108	+ 8.7
12. R. D...	17	40.0	154	1397	1272	+125	+ 9.8
13. A. N...	14	43.0	149	1525	1309	+216	+16.5
14. K. W...	17	44.3	154	1525	1331	+194	+14.6
15. L. Z....	16	57.5	160	1636	1550	+ 86	+ 5.5
16. B......	16	57.5	170	1681	1600	+ 81	+ 5.1
Girls.							
1. A. K...	7	15.3	107	866	967	−101	−10.4
3. A. M...	12	24.0	129	962	1067	−105	− 9.8
4. Fr. W..	12	25.2	128	938	1077	−139	−12.9
5. E. Gl...	13	31.0	138	1217	1146	+ 71	+ 6.2
6. H. Sch..	11	35.0	141	1313	1199	+114	+ 9.5
7. Fr. Th..	14	35.5	143	1299	1194	+105	+ 8.8
9. M. P...	11	42.0	149	1459	1281	+178	+13.9

Turning to the data for youth presented by Magnus-Levy and Falk, the comparison of observed and theoretical values in table 94 shows that without exception the boys are characterized by a higher heat-production than would be expected if metabolism showed the same rate of change from childhood to maturity as it does from maturity to old age, and if the relationship between physical dimensions and metabolism were the same in developing as in mature individuals. The excess ranges from 81 to 297 calories and on the average is 161.1 calories for the 15 boys and youths. On a relative scale, the differences between observation and theory are from 5.1 to 34.7 per cent of the latter, with a general average of 15.6 per cent.

The results for the few girls are not so consistent. As to the reason

for this difference between boys and girls we have no suggestion to offer. It emphasizes the need for more numerous and more minutely recorded data.

It appears that the metabolism is much higher in boyhood than in manhood, but in passing we must note that practically all of Magnus-Levy and Falk's determinations are higher than the American standard. Thus the values of their constants for youth are probably too high (when used in connection with American values for adults) for the plotting of a curve of metabolism throughout life, as has been done by Du Bois.[14]

To avoid all possible misunderstanding concerning the line of reasoning employed in this section, we may reiterate that the age factor in these immature subjects has for *purposes of investigation* been assumed to be given by an extension of the line found valid for the period of adult life. If the measured metabolism of the growing subjects is higher than the value predicted by the standard equation for adult life, we conclude that (if all sources of experimental error were ruled out) the decrease in metabolism rate is much more rapid in the period of growth than in the period of maturity. This seems to be the indication of the series of measurements by Du Bois[15] and Magnus-Levy and Falk.

To show how large an influence correction for age by the adult formula has had upon these metabolism constants we have predicted the metabolism of the young subjects by means of the equations for adult life *ignoring the influence of age changes during adult life itself.* The equations are [16]

For all men............... $h = -314.613 + 13.129\,w + 6.388\,s$
For all women............ $h = 713.016 + 8.063\,w + 1.116\,s$

The results are given in table 95. The first difference column shows that the age term in our equations has made a difference in the predicted value of from 74 to 199 calories per 24 hours.

The second section of the table shows the percentage excess of the measured over the theoretical heat-production when the latter is computed in the two ways. Here there is an influence not merely of the actual differences in calculated and measured heat-production, but of the theoretical heat-productions used as bases for the calculation of the percentage excesses.

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[14] Du Bois, Am. Journ. Med. Sci., 1916, **151**, p. 781. Also Stud. Dep. Physiol., Cornell Univ. Med. Bull., 1917, 6, No. 3, part II, p. 1.

[15] Just as this manuscript was being completed for the press, a second paper on the same subjects appeared (Olmstead, Barr and Du Bois, Arch. Intern. Med., 1918, 21, p. 621). In this investigation they find that the boy scouts had shown a material decrease in metabolism during the two years since they were last studied. The influence of a small breakfast upon metabolism has also been investigated (Soderstrom, Barr, and Du Bois, Arch. Intern. Med., 1918, **21**, p. 613), and the authors conclude that it has no significant influence upon the metabolism constant.

[16] See Chapter VI, p. 184.

The final difference column shows how much greater the excesses are when the age term is ignored and the regression equation involving stature and weight only is used.

We now turn to the problem of the metabolism rate at the other extreme of the life cycle, and shall consider the metabolism of the 6 old men studied by Aub and Du Bois.[17] Table 96 contains the essential measurements and the comparison of the observed heat-production

TABLE 95.—*Comparison of metabolism of boys calculated from adult normal (multiple prediction) standard when the age factor is considered and when it is ignored.*

Name.	Calculated metabolism in calories per 24 hours.			Percentage excess on basis of standard.		
	Age considered.	Age ignored.	Difference.	Age considered.	Age ignored.	Difference.
American boys.						
J. D. D. B.	1225	1116	+109	9.4	20.1	+10.7
Leslie B.	1076	960	+116	20.8	35.4	+14.6
Raymond M.	1102	985	+117	28.4	43.7	+15.3
Reginald F.	1206	1096	+110	23.1	35.5	+12.4
F. R. S.	1131	1014	+117	21.6	35.6	+14.0
Arthur A.	1128	1026	+102	19.5	31.4	+11.9
Harry B.	1206	1099	+107	16.2	27.5	+11.3
Henry K.	1207	1103	+104	18.6	29.8	+11.2
German boys.						
2. M. N.	776	578	+198	19.3	60.2	+40.9
3. Fr. H.	829	630	+199	17.0	54.0	+37.0
4. G. H.	844	653	+191	26.4	63.4	+37.0
5. K. W.	856	661	+195	34.7	74.4	+39.7
6. E. J.	881	706	+175	17.6	46.7	+29.1
7. P. Oe.	1002	857	+145	14.9	34.3	+19.4
8. A. T.	1075	924	+151	24.6	44.8	+20.2
9. O. Gr.	1179	1066	+113	11.1	22.9	+11.8
10. E. K.	1188	1076	+112	8.2	19.4	+11.2
11. K. Ke.	1244	1153	+ 91	8.7	17.3	+ 8.6
12. R. D.	1272	1194	+ 78	9.8	17.0	+ 7.2
13. A. N.	1309	1202	+107	16.5	26.9	+10.4
14. K. W.	1331	1251	+ 80	14.6	21.9	+ 7.3
15. L. Z.	1550	1462	+ 88	5.5	11.9	+ 6.4
16. B.	1600	1526	+ 74	5.1	10.2	+ 5.1

in calories per 24 hours (indirect calorimetry) with the values predicted by the use of our formula from the constants for body-weight, stature, and age.

The difference column shows that our formula has in all cases but one predicted a lower metabolism for these subjects than that found by actual observation. The difference between observation and theory in these 5 cases is rather large, amounting to about 245 calories per 24 hours.

For comparison we may show the results of applying our equations to the physical measurements of the old men and women studied by

[17] Aub and Du Bois, Arch. Intern. Med., 1917, **19**, p. 823.

Magnus-Levy and Falk.[18] The comparison of observed and theoretical values in table 97 shows that with one exception the observed are higher than the calculated values. The differences range from 2.2 to 27.5 per cent higher than the standard. The results tend, therefore, to confirm those of Aub and Du Bois. At first glance this might seem to indicate that our formula is erroneous, at least when applied to individuals falling quite outside the age range covered by the series of observations upon which it is based. We make no claim whatever for the strict validity of our formula in extreme old age. Such a claim can only be made when far more extensive series of old men and women are included in the standard series.

TABLE 96.—*Comparison of metabolism of old men studied by Aub and Du Bois with adult normal (multiple prediction) standard.*

Name.	Age.	Weight in kilograms.	Height in centimeters.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.
Andrew O'C....	77	69.7	171	1600	1360	+240
Henry L........	78	68.9	167	1568	1323	+245
Charles H......	79	52.9	163	1416	1076	+340
Charles W......	80	69.1	164	1220	1297	− 77
William C......	83	62.9	163	1426	1186	+240
John B.........	83	50.5	158	1240	991	+249

TABLE 97.—*Comparison of metabolism of old men and women (German) measured by Magnus-Levy and Falk with American normal (multiple prediction) standard.*

Name and number.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Old men.							
1. A. Kr....	71	47.8	164	1124	1065	+ 59	+ 5.5
2. Be......	70	60.0	165	1320	1244	+ 76	+ 6.1
3. Ki.......	78	68.5	162	1215	1292	− 77	− 6.0
4. Wa......	77	69.3	172	1479	1360	+119	+ 8.8
5. He......	64	70.4	160	1760	1403	+357	+25.4
Old women.							
4. Kl......	71	49.5	145	1088	1065	+ 23	+ 2.2
5. Schm....	83	51.0	146	1307	1025	+282	+27.5
7. Schä.....	86	59.3	150	1143	1098	+ 45	+ 4.1

In emphasizing the fact that our equations predict a metabolism for these octogenarians below their observed heat-productions we must point out that exactly the same relationship is found if the original line as drawn by Du Bois is used. Thus in the explanation of their figure 1, Aub and Du Bois remark:[19] "In accordance with the findings in the present series, the line is somewhat higher in old age than in

[18] Magnus-Levy and Falk, *loc. cit.*
[19] Aub and Du Bois, Arch. Intern. Med., 1917, **19**, p. 824.

the curves published in previous papers." Thus their earlier diagram agrees with our equation in indicating that the observed metabolism of these old men is abnormally high. The remarkable agreement of 5 of the men in their figure 2 with the old-age portion of their line and the obvious bad results with our equation are, therefore, due to the fact that their prediction line has been redrawn to fit the special observations, while our own has not.

The explanation of these results is a problem of considerable difficulty. Of course, one thinks first of all of the question of muscular repose. Were these octogenarians as quiet as the younger individuals with whom they are compared? We must note that even for the years of maturity the constants of Magnus-Levy and Falk are higher than the American standards. If this result be due to faulty technique it may account for the high values of the old men and women measured by them.

It seems to us quite as possible that the discrepancy indicates not the invalidity of our formula but the selected character of the 6 old men studied by Aub and Du Bois. In the course of their discussion they remark:

> "It will be noted that the metabolism of Charles W. was unusually low. This may be accounted for by the fact that he was much more senile than the others. While this finding is of importance in showing the great depression in metabolism which may occur in old age, we are not justified in using it to obtain the average figure which represents the heat-production of men of his age. . . . . The results on Charles W. show a deviation of 21 per cent from the average of the other old men. He is therefore excluded from the averages as the result of the rule which debars an observation in which the deviation from the mean is greater than 4 times the average deviation."

Our formula gives the metabolism of Charles W. within slightly more than 77 calories per day, or with an error of only 5.9 per cent of the calculated metabolism. On purely general grounds there seems to be no more reason to exclude Charles W. because he was too senile for his age than to exclude the other 5 men because they were too juvenile for their age.[20]

It must not be forgotten that men who reach 75 or 80 years are by virtue of this very fact a selected class. By this time a large proportion of humanity has succumbed to the wear and tear of life. Few are able to totter forward many paces further. Those who march with vigor are not typical of their age. But in selecting subjects for metabolism work, individuals in presumably good health are chosen. In examining the case-histories of the old men studied by Aub and Du Bois one is rather impressed by the idea that they must have been physically very remarkable individuals. Certainly in reading that

[20] If Charles W. is to be excluded, this should certainly have been done before his metabolism was measured.

Andrew O'C. had never been sick until 75 years of age, and that during most of his life he drank about a pint of whiskey a day, that ten of the brothers and sisters of Charles H. lived to be over 70 years of age, that Charles W. at 80 "was formerly very alcoholic," that the health of William C. has always been good, and that the mother of John B., 83 years old, died at 93, the biologist must feel that the octogenarians upon whom this series of determinations was based must have been in their prime men of rare physical capacity.

If this suggestion of the strong influence of selection in the case of old men and women be valid, one might expect that a standard based on a period of life in which selection is not such an important factor would give values lower than the actually measured heat-productions of old age. The anomalous results (in comparison with our standards) of these two independent series of measurements on old people show the pressing need for further investigations of metabolism at the maximum age. We of course freely admit the possibility that our standards may be inadequate for this period. If so, the equations must be modified. We hope that data on this problem may be secured at an early date. Divergence of results of different observers has shown by a comparison with our normal standards of illustrations A and B, how great is the danger of combining the results of different series in order to obtain a curve of the change of metabolism with age as has been done by Du Bois.

ILLUSTRATION C. METABOLISM OF INDIVIDUALS OF ABERRANT PHYSICAL FORM.

We now turn to the problem of the basal metabolism of individuals of highly aberrant physique. For this purpose we avail ourselves of

TABLE 98.—*Comparison of the metabolism of dwarfs as studied by Aub, Du Bois, McCrudden, and Lusk with normal (multiple prediction) standard for men.*

Name.	Subject.	Age.	Height in centimeters.	Weight in kilograms.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.
Patrick W...	Rachitic dwarf.	38	124	37.31	1180	943	−237
Raphael De P	Achondroplasia	35	135	40.86	1256	1067	−189
Samuel G....	Achondroplasia	29	124	34.92	1266	971	−295
Irwin E.....	Myxedema....	32	134	37.37	828	1035	+207
George F....	Hypopituitary. Hypothyroid..	48	149	53.05	1159	1217	+ 58
J. P.*.......	Intestinal...... Infantilism....	17	113	21.3	733	810	+ 77

* J. P. was studied by McCrudden and Lusk, the others are due to Aub and Du Bois.

the data for dwarfs published by Aub and Du Bois [21] and the single dwarf studied by McCrudden and Lusk.[22] Table 98 gives the essential data and the comparison of the theoretical and measured heat-produc-

[21] Aub and Du Bois, Arch. Intern. Med., 1917, 19, p. 840.
[22] McCrudden and Lusk, Journ. Biol. Chem., 1912–13, 13, p. 447.

tions for 24-hour periods. In 3 instances our formula has predicted too large and in 3 cases too small a daily heat-production. The average error without regard to sign is 177 calories, but with regard to sign it is −63 calories per day. Thus, while in the individual instance the error of prediction may be fairly large, the average result is, considering the small number of subjects, reasonably close. Physiologically the comparison suggests that the metabolism of dwarfs is essentially the same as that of normal adults.

Illustration D. Metabolism of Athletes.

As an example of the application of these equations, or tables, in the solution of a specific physiological problem, we may take the data for a series of 16 athletes[23] studied in the Chemical Laboratory of Syracuse University by Dr. H. Monmouth Smith, now of the Nutrition Laboratory staff. These all fall well within the age range of our equation, and an observed deviation from the standard values can not in this case be attributed to a distinct difference in metabolism due to age, as is certainly the case in the series of boy scouts studied by Du Bois, or to *possible* inadequacy of our formulas for extreme old age, as in the octogenarians recorded by Aub and Du Bois.

Table 99.—*Comparison of basal metabolism of H. Monmouth Smith's athletes with adult male normal (multiple prediction) standard.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
M. A. M. . .	29	66.0	177	1695	1664	+ 31	+1.9
F. G. R. . . .	20	74.0	179	1914	1845	+ 69	+3.7
W. F. M . . .	21	62.4	180	1816	1683	+133	+7.9
E. G.	20	78.9	184	2126	1937	+189	+9.8
D. H. W . . .	22	82.1	186	2034	1977	+ 57	+2.9
J. H. R.	23	82.2	187	1978	1977	+ 1	+0.1
M. H. K. . .	19	79.0	188	1944	1965	− 21	−1.1
H. W.	19	108.9	198	2559	2426	+133	+5.5
C. J. D.	27	56.7	160	1524	1464	+ 60	+4.1
W. S.	22	88.5	165	2017	1960	+ 57	+2.9
W. A. S. . . .	21	56.3	169	1562	1544	+ 18	+1.2
R. D. S. . . .	21	63.5	170	1619	1648	− 29	−1.8
M. Y. B. . . .	20	63.5	172	1677	1665	+ 12	+0.7
C. D. R. . . .	22	74.0	173	1908	1801	+107	+5.9
H. R. W. . .	24	73.9	175	1842	1796	+ 46	+2.6
P. D. F. . . .	23	71.2	176	1810	1771	+ 39	+2.2

Table 99 gives the age, weight, and stature, from which the theoretical basal metabolism of the men has been calculated and entered in the fifth column of the table. As is clearly shown by the entries in the sixth and seventh columns, *the athletes are, with two slight exceptions, supernormal in their metabolism.* The excesses over the standard values range from 1 to 189 calories per 24 hours, or from 0.1 to 9.8 per cent

[23] Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 243.

of the standard value. On an average the athletes show an excess of 56.37 calories or 3.03 per cent over the standard. These results fully confirm the conclusions concerning the influence of athletic training already drawn, although the percentage differences are materially lower by the new methods of analysis.

The authors [24] expressed their results for selected groups of athletes and of non-athletic individuals in terms of heat-production per 24 hours per square meter of body-surface as estimated by the Meeh formula and on the average found for athletes 863 calories and for non-athletes 807 calories. Thus athletes were 6.84 per cent higher. Subsequent revision of these calculations on the basis of the Du Bois height-weight chart shows 978 calories for athletes and 912 calories for non-athletes. Thus the athletes are 7.24 per cent higher.

By the method of analysis here employed we find a difference of only 3 per cent. This difference in percentage results is probably due to (1) the inherent defects in the selected-group system of comparison which have been pointed out above; and (2) to including athletes in the data from which the normal standard was derived. Had athletes been excluded from the standard normal series the differences would have been greater. Why, therefore, were they not excluded? Because athletic training is in some degree characteristic of men at large. Blacksmiths, riveters, stone-masons, lumbermen, cowboys, miners, and stevedores are quite as typically men as are bar-tenders, book-keepers, floor-walkers, and college professors. Out of 136 men, 16 with special athletic training is perhaps not too large a proportion for a series which is intended to serve as a standard for normal men, in good health, as a class.

Illustration E. Metabolism of Vegetarians.

As a further illustration of the applicability of these equations in human physiology, we may consider the metabolism of vegetarians, a question which has already been discussed elsewhere [25] on the basis of a series of men and women well within the age-range over which our equations may be held to apply. The observed daily heat-productions are compared with the standard productions in table 100 for men and in table 101 for women. Of the 11 men, 6 show a subnormal and 5 show a supernormal metabolism. Of the 11 women, 5 are characterized by a subnormal and 6 by a supernormal metabolism. Disregarding sex, as we may quite properly do since it has been taken into account in the equations used, we note that 11 vegetarians have a subnormal and 11 have a supernormal metabolism. The average metabolism of the 11 men is subnormal by 24.64 calories per 24 hours, whereas that of the women is supernormal by 5.91 calories per 24 hours. Disregarding sex, the metabolism of vegetarians differs from the multiple

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[24] Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 251, Table II.

[25] Benedict and Roth, Journ. Biol. Chem., 1915, **20**, p. 231.

prediction standard values for individuals of like sex, age, weight, and stature, on the average by 9.37 calories per 24 hours. These results furnish a full substantiation for the conclusion already drawn:[26] "We may, therefore, fairly conclude that living upon a vegetarian diet for a longer or shorter period does not fundamentally alter the basal gaseous metabolism."

TABLE 100.—*Comparison of basal metabolism of Roth's male vegetarians with normal (multiple prediction) standard for men.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
B. K.	39	58.2	178	1393	1494	−101	−6.8
B. N. C.	32	50.6	179	1510	1442	+ 68	+4.7
L. H. W.	27	60.0	179	1530	1605	− 75	−4.7
E. J. W.	58	50.0	155	1158	1138	+ 20	+1.8
V. E. H.	21	49.3	163	1365	1418	− 53	−3.7
Dr. P. R.	41	55.2	164	1341	1369	− 28	−2.0
F. E. M.	38	75.0	164	1698	1662	+ 36	+2.2
W. B. L.	29	59.3	164	1451	1507	− 56	−3.7
T. H. Y.	22	59.2	169	1605	1578	+ 27	+1.7
E. H. T.	25	64.7	170	1499	1638	−139	−8.5
O. N. A.	25	55.4	171	1545	1515	+ 30	+2.0

TABLE 101.—*Comparison of metabolism of Roth's female vegetarians with normal (multiple prediction) standard for women.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Miss O. A.	21	90.2	164	1756	1723	+ 33	+ 1.9
Mrs. E. B.	53	58.0	163	1415	1263	+152	+12.0
Miss J. N. B.	26	53.8	160	1215	1344	−129	− 9.6
Miss L. B.	27	47.0	167	1168	1287	−119	− 9.2
Dr. M. D.	44	93.6	165	1765	1650	+115	+ 7.0
Miss M. H.	27	49.1	151	1178	1278	−100	− 7.8
Miss M. J.	27	44.8	157	1189	1248	− 59	− 4.7
Miss L. K.	22	56.8	166	1365	1402	− 37	− 2.6
Mrs. A. L.	29	44.9	159	1272	1243	+ 29	+ 2.3
Miss J. T.	36	40.0	168	1269	1180	+ 89	+ 7.5
Miss C. Z.	39	67.2	170	1521	1430	+ 91	+ 6.4

ILLUSTRATION F. METABOLISM IN DISEASE.

The purpose of many clinical calorimetric researches is to determine whether a significant modification of metabolism is associated with the specific disease under investigation. To solve this problem one must compare the actually measured calories of the subject with the calories calculated from weight, stature, and age on the assumption that he is in normal health. To illustrate the applicability of these equations (or tables) to such pathological problems, we may avail ourselves of Dr. Elliott P. Joslin's series of diabetics.[27]

[26] Benedict and Roth, *loc. cit.*, p. 240.
[27] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912.

Table 102 gives the key number of the subjects,[28] their age, weight, stature, and actually measured basal heat-production for 24-hour periods. The fifth column gives the theoretical heat-production, the sixth the absolute deviation of the measured from the calculated, and the seventh the relative deviation of the actually determined from the theoretical (normal) heat-production.

TABLE 102.—*Metabolism of Joslin's series of diabetics in comparison with normal (multiple prediction) standard.*

Subject.	Age.	Weight.	Stature.	Actual daily heat-production.	Calculated daily heat-production.	Actual less calculated metabolism.	Percentage difference.
Men.							
A(2)	49	51.6	171	1481	1301	+180	+13.8
A(1)	50	46.1	171	1255	1218	+ 37	+ 3.0
C(1)	30	55.5	166	1610	1458	+152	+10.4
C (2)	30	62.7	166	1728	1557	+171	+11.0
D	31	48.8	173	1382	1394	− 12	− 0.9
G	34	67.1	178	1978	1650	+328	+19.9
I	25	40.0	176	1608	1328	+280	+21.1
J	21	54.0	171	1670	1523	+147	+ 9.7
K (2)	46	59.1	180	1596	1469	+127	+ 8.6
K (1)	47	55.6	180	1728	1414	+314	+22.2
L (2)	22	63.0	183	1898	1700	+198	+11.6
L (1)	24	66.5	183	1884	1734	+150	+ 8.7
N	14	31.5	146	1186	1136	+ 50	+ 4.4
P	17	40.0	173	1414	1367	+ 47	+ 3.4
Q	15	51.7	168	1538	1517	+ 21	+ 1.4
R	48	55.3	181	1812	1408	+404	+28.7
S	57	58.0	177	1428	1365	+ 63	+ 4.6
T	44	51.4	180	1553	1377	+176	+12.8
V	36	60.0	173	1894	1514	+380	+25.1
Women.							
B	40	41.4	158	1195	1156	+ 39	+ 3.4
H	38	52.4	159	1440	1273	+167	+13.1
O	16	52.6	173	1498	1403	+ 95	+ 6.8
U	37	39.5	160	1385	1156	+229	+19.8

With one single exception *of 12 calories per 24 hours* in the case of subject D, the observed are all higher than the theoretical metabolism constants. The excess ranges from 21 to 404 calories per 24 hours in men and from 39 to 229 calories in women. In relation to the computed heat-production taken as a standard, the excess in the men ranges from 1.4 to 28.7 per cent. In the women the range is from 3.4 to 19.8 per cent. The average deviation of the 19 male determinations is 169.11 calories, while the average deviation of the 4 female determinations is 132.50 calories. On the average the heat productions of the men are 11.55 per cent above normal, whereas those for the women are 10.78 per cent above normal.

These results are fully confirmatory of the general conclusions

[28] Observations on the same patient at different ages or different body-weights are in some cases available. These are recorded as 1 and 2.

already drawn.[29] Here the application of the formulas to diabetics serves merely as a particular example of a general method.

It may not be out of place, however, to look at certain quantitative aspects of the subject more closely. On examining the increments in metabolism due to diabetes found by this method, we note that they are on the average only about 11 per cent as compared with 15 to 20 per cent as asserted in earlier publications from the Nutrition Laboratory.[30] In partial explanation of this percentage difference we may note that our prediction equation for men includes about 16 athletes. This represents about 12 per cent of the whole control series. But in a preceding illustration we have shown that athletes themselves have a higher metabolism than normal men at large. Our reasons for including athletes in our standard series have been given above. It should be a fixed scientific principle that standards should not be changed whenever convenience demands.[31] The inevitable consequence of this inclusion of the athletes has been to reduce the percentage difference between diabetics and non-diabetics. In short, it has made the comparison as disadvantageous as possible to the views concerning diabetes long held at the Nutrition Laboratory. Notwithstanding this fact, the validity of the general conclusions already drawn is fully supported.

A study of the individual entries in this table has considerable value as indicating the limits of trustworthiness of conclusions from *single* subjects even when compared with a standard control based on large numbers. For example, had the one subject examined chanced to be *D* the incautious clinician might have concluded that diabetes decreases metabolism. Had the second subject chanced to be *Q* he might have concluded that a defect of 12 calories in one case and an excess of 21 calories in the other indicated no relationship at all between diabetes and metabolism. Had *V* or *R* been the only subject examined, a quite exaggerated impression of the influence of diabetes might have been drawn, for these men show an excess of 25.1 and 28.7 per cent. *It is only when a considerable number of pathological cases are available for comparison with the standard that dependable conclusions concerning the influence of any disease can be drawn.* This principle is a fundamental one, and must be applied in all comparisons of special groups with standard control series in all nutritional research.

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[29] Benedict and Joslin, *loc. cit.*, p. 121.

[30] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 193; also Carnegie Inst. Wash. Pub. No. 176, 1912, p. 121.

[31] Criticism has been made from the Nutrition Laboratory of the Du Bois method of excluding undersized individuals in obtaining their normal, and the specific statement has been made that we should not compare standard normals based primarily upon robust, vigorous individuals with emaciated, weak, under-weight diabetics. We still hold these criticisms to be valid, and we have avoided them in the comparisons in table 102 by utilizing equations which enable one to compare each diabetic with a standard value for an individual of like height, weight, and age. But in determining the equations for *these* standard values we have included athletes among the normals, *even though their inclusion has minimized the difference between diabetic and non-diabetic individuals.*

ILLUSTRATION G. RATIONING IN PERIODS OF EMERGENCY.

The problem of rationing in national crises involves so many factors (biological, social, and economic) that general principles only can be established.

It is evident, however, that the fairest and the most advantageous plan for the allotment of rations is that which is based on the physiological needs of the individuals of the population under consideration. For instance in an editorial [32] on the Inter-Allied Scientific Food Commission we read:

"The basal heat production of an average man weighing 156 pounds (70 kg.) will be 70 calories an hour at rest and without food, or 1680 calories in twenty-four hours."

Body-weight is not, however, an adequate standard. The analysis in the present volume shows that stature, weight, and age must all be taken into account in determining the basal metabolism of the individual, and hence in determining most exactly the food requirements of a population.

Our 136 men show an average weight of 64.1 kilograms instead of the 70 kilograms ordinarily assumed as an average value. They show an average basal metabolism of 1632 calories as compared with 1680 calories. Our men are on the average 26.9 years of age and 173 centimeters in height. If we assume that the men of a population average 70 kg. in weight, 170 cm. in stature, and 35 years of age, we find from tables I and II a basal requirement of $1029+614=1643$ calories. If we are considering a population of adult women weighing on the average 56.0 kg., 162 cm. in height, and 35 years of age the values from tables III and IV are $1191+136=1327$ calories.

These factors must, in practical rationing, be multiplied by the requisite factors for the increased metabolism due to muscular and other activity.

4. RECAPITULATION.

The purpose of this chapter, in which the principles underlying the establishment of standard control series have been discussed, has been three-fold.

1. To emphasize the necessity for the establishment of statistical normal basal metabolism standards, which may serve as a basis of comparison in all special nutritional investigations.

2. To supply convenient tables of such standards based on the most extensive series of normal data as yet available.

3. To illustrate the practical use of such tables in the solution of problems in nutritional physiology.

The analysis of this and the preceding chapters leads to the conclusion that biologically the most rational and practically the most satis-

[32] Journ. Am. Med. Ass., 1918, **71**, p. 1660. Incompletely quoting Lusk, Journ. Am. Med. Ass., 1918, **70**, p. 821.

factory standard is that secured by taking into account the body-weight, stature, and age of the subject in predicting basal metabolism. This method is therefore an extension and modification of the *selected group method*, employed earlier at the Nutrition Laboratory. In the new method, which we have designated as the *multiple-prediction method*, we replace the empirical determinations of the metabolism of individuals of specific weight, stature, and age by values given by *multiple prediction equations* based on the statistical constants of all available normal data.

These equations have been tabled for both men and women for a range of weight, stature, and age which will be met in practical work with adult subjects, and give a set of *multiple prediction tables of standard normal adult basal metabolism constants.*

The illustrations of the practical application of these multiple prediction tables show first of all their great usefulness in the detection of differences between series of metabolism measurements. Thus, as far as we are aware, the anomalous nature of the series of determinations by Magnus-Levy and Falk and those by Palmer, Means, and Gamble, has heretofore quite escaped the notice of physiologists, and their data have been combined freely with other series for the purpose of generalization. The aberrant nature of these series becomes evident as soon as comparison of the actual measurements with the theoretical values from the multiple prediction tables is made.

The use of the tables shows the clear differentiation of athletes and diabetics from other individuals in their metabolic level, thus confirming conclusions already drawn at the Nutrition Laboratory.

The use of the standards shows the existence of a well-marked differentiation in the level of metabolism of men and women, and shows that the differences are persistent throughout adult life instead of disappearing in later years as maintained by Sondén and Tigerstedt. There is no evidence for such differentiation in new-born infants.

While the novelty of the conception underlying these standards will probably limit somewhat their immediate adoption by physiologists, the illustrations show that for purposes of more refined analysis they have great practical value. We believe that ultimately the great convenience of these multiple prediction tables will result in their general adoption as standards of reference in all work on human nutritional physiology.

When larger series of basal data are available we expect to revise these tables so that they may represent the broadest and most secure foundation for comparative nutritional investigation.

APPENDIX.

STANDARD
MULTIPLE PREDICTION TABLES
FOR
NORMAL BASAL METABOLISM

(For method of use see page 230. Chapter VIII gives illustrations of practical application).

TABLE I.—*Factor for body-weight in men.*

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
25	410	412	413	414	416	417	419	420	421	423
26	424	425	427	428	430	431	432	434	435	436
27	438	439	441	442	443	445	446	447	449	450
28	452	453	454	456	457	458	460	461	463	464
29	465	467	468	469	471	472	474	475	476	478
30	479	480	482	483	485	486	487	489	490	491
31	493	494	496	497	498	500	501	502	504	505
32	507	508	509	511	512	513	515	516	518	519
33	520	522	523	524	526	527	529	530	531	533
34	534	535	537	538	540	541	542	544	545	546
35	548	549	551	552	553	555	556	557	559	560
36	562	563	564	566	567	568	570	571	573	574
37	575	577	578	579	581	582	584	585	586	588
38	589	590	592	593	595	596	597	599	600	601
39	603	604	606	607	608	610	611	612	614	615
40	617	618	619	621	622	623	625	626	628	629
41	630	632	633	634	636	637	639	640	641	643
42	644	645	647	648	650	651	652	654	655	656
43	658	659	661	662	663	665	666	667	669	670
44	672	673	674	676	677	678	680	681	683	684
45	685	687	688	689	691	692	694	695	696	698
46	699	700	702	703	705	706	707	709	710	711
47	713	714	716	717	718	720	721	722	724	725
48	727	728	729	731	732	733	735	736	738	739
49	740	742	743	744	746	747	749	750	751	753
50	754	755	757	758	760	761	762	764	765	766
51	768	769	771	772	773	775	776	777	779	780
52	782	783	784	786	787	788	790	791	793	794
53	795	797	798	799	801	802	804	805	806	808
54	809	810	812	813	815	816	817	819	820	821
55	823	824	826	827	828	830	831	832	834	835
56	837	838	839	841	842	843	845	846	848	849
57	850	852	853	854	856	857	859	860	861	863
58	864	865	867	868	870	871	872	874	875	876
59	878	879	881	882	883	885	886	887	889	890
60	892	893	894	896	897	898	900	901	903	904
61	905	907	908	909	911	912	914	915	916	918
62	919	920	922	923	925	926	927	929	930	931
63	933	934	936	937	938	940	941	942	944	945
64	947	948	949	951	952	953	955	956	958	959
65	960	962	963	964	966	967	969	970	971	973
66	974	975	977	978	980	981	982	984	985	986
67	988	989	991	992	993	995	996	997	999	1000
68	1002	1003	1004	1006	1007	1008	1010	1011	1013	1014
69	1015	1017	1018	1019	1021	1022	1024	1025	1026	1028
70	1029	1030	1032	1033	1035	1036	1037	1039	1040	1041
71	1043	1044	1046	1047	1048	1050	1051	1052	1054	1055
72	1057	1058	1059	1061	1062	1063	1065	1066	1068	1069
73	1070	1072	1073	1074	1076	1077	1079	1080	1081	1083
74	1084	1085	1087	1088	1090	1091	1092	1094	1095	1096

TABLE I.—*Factor for body-weight in men.*—Concluded.

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
75	1098	1099	1101	1102	1103	1105	1106	1107	1109	1110
76	1112	1113	1114	1116	1117	1118	1120	1121	1123	1124
77	1125	1127	1128	1129	1131	1132	1134	1135	1136	1138
78	1139	1140	1142	1143	1145	1146	1147	1149	1150	1151
79	1153	1154	1156	1157	1158	1160	1161	1162	1164	1165
80	1167	1168	1169	1171	1172	1173	1175	1176	1178	1179
81	1180	1182	1183	1184	1186	1187	1189	1190	1191	1193
82	1194	1195	1197	1198	1200	1201	1202	1204	1205	1206
83	1208	1209	1211	1212	1213	1215	1216	1217	1219	1220
84	1222	1223	1224	1226	1227	1228	1230	1231	1233	1234
85	1235	1237	1238	1239	1241	1242	1244	1245	1246	1248
86	1249	1250	1252	1253	1255	1256	1257	1259	1260	1261
87	1263	1264	1266	1267	1268	1270	1271	1272	1274	1275
88	1277	1278	1279	1281	1282	1283	1285	1286	1288	1289
89	1290	1292	1293	1294	1296	1297	1299	1300	1301	1303
90	1304	1305	1307	1308	1310	1311	1312	1314	1315	1316
91	1318	1319	1321	1322	1323	1325	1326	1327	1329	1330
92	1332	1333	1334	1336	1337	1338	1340	1341	1343	1344
93	1345	1347	1348	1349	1351	1352	1354	1355	1356	1358
94	1359	1360	1362	1363	1365	1366	1367	1369	1370	1371
95	1373	1374	1376	1377	1378	1380	1381	1383	1384	1385
96	1387	1388	1389	1391	1392	1394	1395	1396	1398	1399
97	1400	1402	1403	1405	1406	1407	1409	1410	1411	1413
98	1414	1416	1417	1418	1420	1421	1422	1424	1425	1427
99	1428	1429	1431	1432	1433	1435	1436	1438	1439	1440
100	1442	1443	1444	1446	1447	1449	1450	1451	1453	1454
101	1455	1457	1458	1460	1461	1462	1464	1465	1466	1468
102	1469	1471	1472	1473	1475	1476	1477	1479	1480	1482
103	1483	1484	1486	1487	1488	1490	1491	1493	1494	1495
104	1497	1498	1499	1501	1502	1504	1505	1506	1508	1509
105	1510	1512	1513	1515	1516	1517	1519	1520	1521	1523
106	1524	1526	1527	1528	1530	1531	1532	1534	1535	1537
107	1538	1539	1541	1542	1543	1545	1546	1548	1549	1550
108	1552	1553	1554	1556	1557	1559	1560	1561	1563	1564
109	1565	1567	1568	1570	1571	1572	1574	1575	1576	1578
110	1579	1581	1582	1583	1585	1586	1587	1589	1590	1592
111	1593	1594	1596	1597	1598	1600	1601	1603	1604	1605
112	1607	1608	1609	1611	1612	1614	1615	1616	1618	1619
113	1620	1622	1623	1625	1626	1627	1629	1630	1631	1633
114	1634	1636	1637	1638	1640	1641	1642	1644	1645	1647
115	1648	1649	1651	1652	1653	1655	1656	1658	1659	1660
116	1662	1663	1664	1666	1667	1669	1670	1671	1673	1674
117	1675	1677	1678	1680	1681	1682	1684	1685	1686	1688
118	1689	1691	1692	1693	1695	1696	1697	1699	1700	1702
119	1703	1704	1706	1707	1708	1710	1711	1713	1714	1715
120	1717	1718	1719	1721	1722	1724	1725	1726	1728	1729
121	1730	1732	1733	1735	1736	1737	1739	1740	1741	1743
122	1744	1746	1747	1748	1750	1751	1752	1754	1755	1757
123	1758	1759	1761	1762	1763	1765	1766	1768	1769	1770
124	1772	1773	1774	1776	1777	1779	1780	1781	1783	1784

TABLE II.—*Factor for stature and age in men.*

	21	22	23	24	25	26	27	28	29	30
151	614	607	600	593	587	580	573	566	560	553
152	619	612	605	598	592	585	578	571	565	558
153	624	617	610	603	597	590	583	576	570	563
154	629	622	615	608	602	595	588	581	575	568
155	634	627	620	613	607	600	593	586	580	573
156	639	632	625	618	612	605	598	591	585	578
157	644	637	630	623	617	610	603	596	590	583
158	649	642	635	628	622	615	608	601	595	588
159	654	647	640	633	627	620	613	606	600	593
160	659	652	645	638	632	625	618	611	605	598
161	664	657	650	643	637	630	623	616	610	603
162	669	662	655	648	642	635	628	621	615	608
163	674	667	660	653	647	640	633	626	620	613
164	679	672	665	658	652	645	638	631	625	618
165	684	677	670	663	657	650	643	636	630	623
166	689	682	675	668	662	655	648	641	635	628
167	694	687	680	673	667	660	653	646	640	633
168	699	692	685	678	672	665	658	651	645	638
169	704	697	690	683	677	670	663	656	650	643
170	709	702	695	688	682	675	668	661	655	648
171	714	707	700	693	687	680	673	666	660	653
172	719	712	705	698	692	685	678	671	665	658
173	724	717	710	703	697	690	683	676	670	663
174	729	722	715	708	702	695	688	681	675	668
175	734	727	720	713	707	700	693	686	680	673
176	739	732	725	718	712	705	698	691	685	678
177	744	737	730	723	717	710	703	696	690	683
178	749	742	735	728	722	715	708	701	695	688
179	754	747	740	733	727	720	713	706	700	693
180	759	752	745	738	732	725	718	711	705	698
181	764	757	750	743	737	730	723	716	710	703
182	769	762	755	748	742	735	728	721	715	708
183	774	767	760	753	747	740	733	726	720	713
184	779	772	765	758	752	745	738	731	725	718
185	784	777	770	763	757	750	743	736	730	723
186	789	782	775	768	762	755	748	741	735	728
187	794	787	780	773	767	760	753	746	740	733
188	799	792	785	779	772	765	758	751	745	738
189	804	797	790	784	777	770	763	756	750	743
190	809	802	795	789	782	775	768	761	755	748
191	814	807	800	794	787	780	773	766	760	753
192	819	812	805	799	792	785	778	771	765	758
193	824	817	810	804	797	790	783	776	770	763
194	829	822	815	809	802	795	788	781	775	768
195	834	827	820	814	807	800	793	787	780	773
196	839	832	825	819	812	805	798	792	785	778
197	844	837	830	824	817	810	803	797	790	783
198	849	842	835	829	822	815	808	802	795	788
199	854	847	840	834	827	820	813	807	800	793
200	859	852	845	839	832	825	818	812	805	798

TABLE II.—*Factor for stature and age in men.*—Continued.

	31	32	33	34	35	36	37	38	39	40
151	546	539	533	526	519	512	506	499	492	485
152	551	544	538	531	524	517	511	504	497	490
153	556	549	543	536	529	522	516	509	502	495
154	561	554	548	541	534	527	521	514	507	500
155	566	559	553	546	539	532	526	519	512	505
156	571	564	558	551	544	537	531	524	517	510
157	576	569	563	556	549	542	536	529	522	515
158	581	574	568	561	554	547	541	534	527	520
159	586	579	573	566	559	552	546	539	532	525
160	591	584	578	571	564	557	551	544	537	530
161	596	589	583	576	569	562	556	549	542	535
162	601	594	588	581	574	567	561	554	547	540
163	606	599	593	586	579	572	566	559	552	545
164	611	604	598	591	584	577	571	564	557	550
165	616	609	603	596	589	582	576	569	562	555
166	621	614	608	601	594	587	581	574	567	560
167	626	619	613	606	599	592	586	579	572	565
168	631	624	618	611	604	597	591	584	577	570
169	636	629	623	616	609	602	596	589	582	575
170	641	634	628	621	614	607	601	594	587	580
171	646	639	633	626	619	612	606	599	592	585
172	651	644	638	631	624	617	611	604	597	590
173	656	649	643	636	629	622	616	609	602	595
174	661	654	648	641	634	627	621	614	607	600
175	666	659	653	646	639	632	626	619	612	605
176	671	664	658	651	644	637	631	624	617	610
177	676	669	663	656	649	642	636	629	622	615
178	681	674	668	661	654	647	641	634	627	620
179	686	679	673	666	659	652	646	639	632	625
180	691	684	678	671	664	657	651	644	637	630
181	696	689	683	676	669	662	656	649	642	635
182	701	694	688	681	674	667	661	654	647	640
183	706	699	693	686	679	672	666	659	652	645
184	711	704	698	691	684	677	671	664	657	650
185	716	709	703	696	689	682	676	669	662	655
186	721	714	708	701	694	687	681	674	667	660
187	726	719	713	706	699	692	686	679	672	665
188	731	724	718	711	704	697	691	684	677	670
189	736	729	723	716	709	702	696	689	682	675
190	741	734	728	721	714	707	701	694	687	680
191	746	739	733	726	719	712	706	699	692	685
192	751	744	738	731	724	717	711	704	697	690
193	756	749	743	736	729	722	716	709	702	695
194	761	754	748	741	734	727	721	714	707	700
195	766	759	753	746	739	732	726	719	712	705
196	771	764	758	751	744	737	731	724	717	710
197	776	769	763	756	749	742	736	729	722	715
198	781	774	768	761	754	747	741	734	727	720
199	786	779	773	766	759	752	746	739	732	725
200	791	785	778	771	764	757	751	744	737	730

TABLE II.—*Factor for stature and age in men.*—Continued.

	41	42	43	44	45	46	47	48	49	50
151	479	472	465	458	452	445	438	431	425	418
152	484	477	470	463	457	450	443	436	430	423
153	489	482	475	468	462	455	448	441	435	428
154	494	487	480	473	467	460	453	446	440	433
155	499	492	485	478	472	465	458	451	445	438
156	504	497	490	483	477	470	463	456	450	443
157	509	502	495	488	482	475	468	461	455	448
158	514	507	500	493	487	480	473	466	460	453
159	519	512	505	498	492	485	478	471	465	458
160	524	517	510	503	497	490	483	476	470	463
161	529	522	515	508	502	495	488	481	475	468
162	534	527	520	513	507	500	493	486	480	473
163	539	532	525	518	512	505	498	491	485	478
164	544	537	530	523	517	510	503	496	490	483
165	549	542	535	528	522	515	508	501	495	488
166	554	547	540	533	527	520	513	506	500	493
167	559	552	545	538	532	525	518	511	505	498
168	564	557	550	543	537	530	523	516	510	503
169	569	562	555	548	542	535	528	521	515	508
170	574	567	560	553	547	540	533	526	520	513
171	579	572	565	558	552	545	538	531	525	518
172	584	577	570	563	557	550	543	536	530	523
173	589	582	575	568	562	555	548	541	535	528
174	594	587	580	573	567	560	553	546	540	533
175	599	592	585	578	572	565	558	551	545	538
176	604	597	590	583	577	570	563	556	550	543
177	609	602	595	588	582	575	568	561	555	548
178	614	607	600	593	587	580	573	566	560	553
179	619	612	605	598	592	585	578	571	565	558
180	624	617	610	603	597	590	583	576	570	563
181	629	622	615	608	602	595	588	581	575	568
182	634	627	620	613	607	600	593	586	580	573
183	639	632	625	618	612	605	598	591	585	578
184	644	637	630	623	617	610	603	596	590	583
185	649	642	635	628	622	615	608	601	595	588
186	654	647	640	633	627	620	613	606	600	593
187	659	652	645	638	632	625	618	611	605	598
188	664	657	650	643	637	630	623	616	610	603
189	669	662	655	648	642	635	628	621	615	608
190	674	667	660	653	647	640	633	626	620	613
191	679	672	665	658	652	645	638	631	625	618
192	684	677	670	663	657	650	643	636	630	623
193	689	682	675	668	662	655	648	641	635	628
194	694	687	680	673	667	660	653	646	640	633
195	699	692	685	678	672	665	658	651	645	638
196	704	697	690	683	677	670	663	656	650	643
197	709	702	695	688	682	675	668	661	655	648
198	714	707	700	693	687	680	673	666	660	653
199	719	712	705	698	692	685	678	671	665	658
200	724	717	710	703	697	690	683	676	670	663

TABLE II.—Factor for stature and age in men.—Continued.

	51	52	53	54	55	56	57	58	59	60
151	411	404	397	391	384	377	370	364	357	350
152	416	409	402	396	389	382	375	369	362	355
153	421	414	407	401	394	387	380	374	367	360
154	426	419	412	406	399	392	385	379	372	365
155	431	424	417	411	404	397	390	384	377	370
156	436	429	422	416	409	402	395	389	382	375
157	441	434	428	421	414	407	400	394	387	380
158	446	439	433	426	419	412	405	399	392	385
159	451	444	438	431	424	417	410	404	397	390
160	456	449	443	436	429	422	415	409	402	395
161	461	454	448	441	434	427	420	414	407	400
162	466	459	453	446	439	432	425	419	412	405
163	471	464	458	451	444	437	431	424	417	410
164	476	469	463	456	449	442	436	429	422	415
165	481	474	468	461	454	447	441	434	427	420
166	486	479	473	466	459	452	446	439	432	425
167	491	484	478	471	464	457	451	444	437	430
168	496	489	483	476	469	462	456	449	442	435
169	501	494	488	481	474	467	461	454	447	440
170	506	499	493	486	479	472	466	459	452	445
171	511	504	498	491	484	477	471	464	457	450
172	516	509	503	496	489	482	476	469	462	455
173	521	514	508	501	494	487	481	474	467	460
174	526	519	513	506	499	492	486	479	472	465
175	531	524	518	511	504	497	491	484	477	470
176	536	529	523	516	509	502	496	489	482	475
177	541	534	528	521	514	507	501	494	487	480
178	546	539	533	526	519	512	506	499	492	485
179	551	544	538	531	524	517	511	504	497	490
180	556	549	543	536	529	522	516	509	502	495
181	561	554	548	541	534	527	521	514	507	500
182	566	559	553	546	539	532	526	519	512	505
183	571	564	558	551	544	537	531	524	517	510
184	576	569	563	556	549	542	536	529	522	515
185	581	574	568	561	554	547	541	534	527	520
186	586	579	573	566	559	552	546	539	532	525
187	591	584	578	571	564	557	551	544	537	530
188	596	589	583	576	569	562	556	549	542	535
189	601	594	588	581	574	567	561	554	547	540
190	606	599	593	586	579	572	566	559	552	545
191	611	604	598	591	584	577	571	564	557	550
192	616	609	603	596	589	582	576	569	562	555
193	621	614	608	601	594	587	581	574	567	560
194	626	619	613	606	599	592	586	579	572	565
195	631	624	618	611	604	597	591	584	577	570
196	636	629	623	616	609	602	596	589	582	575
197	641	634	628	621	614	607	601	594	587	580
198	646	639	633	626	619	612	606	599	592	585
199	651	644	638	631	624	617	611	604	597	590
200	656	649	643	636	629	622	616	609	602	595

TABLE III.—*Factor for body-weight in women.*

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
25	894	895	896	897	898	899	900	901	902	903
26	904	905	906	907	908	909	909	910	911	912
27	913	914	915	916	917	918	919	920	921	922
28	923	924	925	926	927	928	929	930	931	931
29	932	933	934	935	936	937	938	939	940	941
30	942	943	944	945	946	947	948	949	950	951
31	952	953	953	954	955	956	957	958	959	960
32	961	962	963	964	965	966	967	968	969	970
33	971	972	973	974	975	975	976	977	978	979
34	980	981	982	983	984	985	986	987	988	989
35	990	991	992	993	994	995	996	997	997	998
36	999	1000	1001	1002	1003	1004	1005	1006	1007	1008
37	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018
38	1019	1019	1020	1021	1022	1023	1024	1025	1026	1027
39	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037
40	1038	1039	1040	1041	1041	1042	1043	1044	1045	1046
41	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056
42	1057	1058	1059	1060	1061	1062	1062	1063	1064	1065
43	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075
44	1076	1077	1078	1079	1080	1081	1082	1083	1084	1084
45	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094
46	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104
47	1105	1106	1106	1107	1108	1109	1110	1111	1112	1113
48	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123
49	1124	1125	1126	1127	1128	1128	1129	1130	1131	1132
50	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142
51	1143	1144	1145	1146	1147	1148	1149	1150	1150	1151
52	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161
53	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171
54	1172	1172	1173	1174	1175	1176	1177	1178	1179	1180
55	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190
56	1191	1192	1193	1194	1194	1195	1196	1197	1198	1199
57	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209
58	1210	1211	1212	1213	1214	1215	1216	1216	1217	1218
59	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228
60	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238
61	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247
62	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257
63	1258	1259	1260	1260	1261	1262	1263	1264	1265	1266
64	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276
65	1277	1278	1279	1280	1281	1281	1282	1283	1284	1285
66	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295
67	1296	1297	1298	1299	1300	1301	1302	1303	1303	1304
68	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314
69	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324
70	1325	1325	1326	1327	1328	1329	1330	1331	1332	1333
71	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343
72	1344	1345	1346	1347	1347	1348	1349	1350	1351	1352
73	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362
74	1363	1364	1365	1366	1367	1368	1369	1369	1370	1371

TABLE III.—*Factor for body-weight in women.*—Concluded.

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
75	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381
76	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391
77	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
78	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410
79	1411	1412	1413	1413	1414	1415	1416	1417	1418	1419
80	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429
81	1430	1431	1432	1433	1434	1435	1435	1436	1437	1438
82	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448
83	1449	1450	1451	1452	1453	1454	1455	1456	1457	1457
84	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467
85	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477
86	1478	1479	1479	1480	1481	1482	1483	1484	1485	1486
87	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496
88	1497	1498	1499	1500	1501	1501	1502	1503	1504	1505
89	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515
90	1516	1517	1518	1519	1520	1521	1522	1522	1523	1524
91	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534
92	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544
93	1544	1545	1546	1547	1548	1549	1550	1551	1552	1553
94	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563
95	1564	1565	1566	1566	1567	1568	1569	1570	1571	1572
96	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582
97	1583	1584	1585	1586	1587	1588	1588	1589	1590	1591
98	1592	1593	1594	1595	1596	1597	1598	1599	1600	1601
99	1602	1603	1604	1605	1606	1607	1608	1609	1610	1610
100	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620
101	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630
102	1631	1632	1632	1633	1634	1635	1636	1637	1638	1639
103	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649
104	1650	1651	1652	1653	1654	1654	1655	1656	1657	1658
105	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668
106	1669	1670	1671	1672	1673	1674	1675	1676	1676	1677
107	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687
108	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697
109	1698	1698	1699	1700	1701	1702	1703	1704	1705	1706
110	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716
111	1717	1718	1719	1720	1720	1721	1722	1723	1724	1725
112	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735
113	1736	1737	1738	1739	1740	1741	1741	1742	1743	1744
114	1745	1746	1747	1748	1749	1750	1751	1752	1753	1754
115	1755	1756	1757	1758	1759	1760	1761	1762	1763	1763
116	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773
117	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783
118	1784	1785	1785	1786	1787	1788	1789	1790	1791	1792
119	1793	1794	1795	1796	1797	1798	1799	1800	1801	1802
120	1803	1804	1805	1806	1807	1807	1808	1809	1810	1811
121	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821
122	1822	1823	1824	1825	1826	1827	1828	1829	1829	1830
123	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840
124	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850

TABLE IV.—*Factor for stature and age in women.*

	21	22	23	24	25	26	27	28	29	30
151	181	176	172	167	162	158	153	148	144	139
152	183	178	174	169	164	160	155	150	146	141
153	185	180	175	171	166	161	157	152	147	143
154	187	182	177	173	168	163	159	154	149	145
155	189	184	179	174	170	165	160	156	151	146
156	190	186	181	176	172	167	162	158	153	148
157	192	188	183	178	173	169	164	159	155	150
158	194	189	185	180	175	171	166	161	157	152
159	196	191	187	182	177	173	168	163	158	154
160	198	193	188	184	179	174	170	165	160	156
161	199	195	190	186	181	176	172	167	162	158
162	201	197	192	187	183	178	173	169	164	159
163	203	199	194	189	185	180	175	171	166	161
164	205	200	196	191	186	182	177	172	168	163
165	207	202	198	193	188	184	179	174	170	165
166	209	204	199	194	190	185	181	176	171	167
167	211	206	201	197	192	187	183	178	173	169
168	213	208	203	199	194	189	184	180	175	170
169	214	210	205	200	196	191	186	182	177	172
170	216	212	207	202	198	193	188	184	179	174
171	218	213	209	204	199	195	190	185	181	176
172	220	215	211	206	201	197	192	187	183	178
173	222	217	212	208	203	198	194	189	184	180
174	224	219	214	210	205	200	196	191	186	182
175	225	221	216	211	207	202	197	193	188	183
176	227	223	218	213	209	204	199	195	190	185
177	229	225	220	215	210	206	201	196	192	187
178	231	226	222	217	212	208	203	198	194	189
179	233	228	224	219	214	210	205	200	195	191
180	235	230	225	221	216	211	207	202	197	193
181	237	232	227	223	218	213	209	204	199	195
182	238	234	229	224	220	215	210	206	201	196
183	240	236	231	226	222	217	212	208	203	198
184	242	237	233	228	223	219	214	209	205	200
185	244	239	235	230	225	221	216	211	207	202
186	246	241	236	232	227	222	218	213	208	204
187	248	243	238	234	229	224	220	215	210	206
188	250	245	240	236	231	226	221	217	212	207
189	251	247	242	237	233	228	223	219	214	209
190	253	249	244	239	235	230	225	221	216	211
191	255	250	246	241	236	232	227	222	218	213
192	257	252	248	243	238	234	229	224	220	215
193	259	254	249	245	240	235	231	226	221	217
194	261	256	251	247	242	237	233	228	223	219
195	262	258	253	248	244	239	234	230	225	220
196	264	260	255	250	246	241	236	232	227	222
197	266	262	257	252	247	243	238	233	229	224
198	268	263	259	254	249	245	240	235	231	226
199	270	265	261	256	251	247	242	237	232	228
200	272	267	262	258	253	248	244	239	234	230

TABLE IV.—*Factor for stature and age in women.*—Continued.

	31	32	33	34	35	36	37	38	39	40
151	134	130	125	120	116	111	106	102	97	92
152	136	132	127	122	117	113	108	103	99	94
153	138	133	129	124	119	115	110	105	101	96
154	140	135	131	126	121	117	112	107	102	98
155	142	137	132	128	123	118	114	109	104	100
156	144	139	134	130	125	120	116	111	106	102
157	145	141	136	131	127	122	117	113	108	103
158	147	143	138	133	129	124	119	115	110	105
159	149	144	140	135	130	126	121	116	112	107
160	151	146	142	137	132	128	123	118	114	109
161	153	148	143	139	134	129	125	120	115	111
162	155	150	145	141	136	131	127	122	117	113
163	157	152	147	143	138	133	128	124	119	114
164	158	154	149	144	140	135	130	126	121	116
165	160	156	151	146	142	137	132	128	123	118
166	162	157	153	148	143	139	134	129	125	120
167	164	159	155	150	145	141	136	131	127	122
168	166	161	156	152	147	142	138	133	128	124
169	168	163	158	154	149	144	140	135	130	126
170	169	165	160	155	151	146	141	137	132	127
171	171	167	162	157	153	148	143	139	134	129
172	173	169	164	159	154	150	145	140	136	131
173	175	170	166	161	156	152	147	142	138	133
174	177	172	168	163	158	154	149	144	139	135
175	179	174	169	165	160	155	151	146	141	137
176	181	176	171	167	162	157	153	148	143	139
177	182	178	173	168	164	159	154	150	145	140
178	184	180	175	170	166	161	156	152	147	142
179	186	181	177	172	167	163	158	153	149	144
180	188	183	179	174	169	165	160	155	151	146
181	190	185	180	176	171	166	162	157	152	148
182	192	187	182	178	173	168	164	159	154	150
183	194	189	184	180	175	170	165	161	156	151
184	195	191	186	181	177	172	167	163	158	153
185	197	193	188	183	179	174	169	165	160	155
186	199	194	190	185	180	176	171	166	162	157
187	201	196	192	187	182	178	173	168	164	159
188	203	198	193	189	184	179	175	170	165	161
189	205	200	195	191	186	181	177	172	167	163
190	206	202	197	192	188	183	178	174	169	164
191	208	204	199	194	190	185	180	176	171	166
192	210	206	201	196	191	187	182	177	173	168
193	212	207	203	198	193	189	184	179	175	170
194	214	209	205	200	195	191	186	181	176	172
195	216	211	206	202	197	192	188	183	178	174
196	218	213	208	204	199	194	190	185	180	175
197	219	215	210	205	201	196	191	187	182	177
198	221	217	212	207	203	198	193	189	184	179
199	223	218	214	209	204	200	195	190	186	181
200	225	220	216	211	206	202	197	192	188	183

TABLE IV.—*Factor for stature and age in women.*—Continued.

	41	42	43	44	45	46	47	48	49	50
151	88	83	78	74	69	64	60	55	50	46
152	89	85	80	75	71	66	61	57	52	47
153	91	87	82	77	73	68	63	59	54	49
154	93	88	84	79	74	70	65	60	56	51
155	95	90	86	81	76	72	67	62	58	53
156	97	92	87	83	78	73	69	64	59	55
157	99	94	89	85	80	75	71	66	61	57
158	101	96	91	87	82	77	72	68	63	58
159	102	98	93	88	84	79	74	70	65	60
160	104	100	95	90	86	81	76	72	67	62
161	106	101	97	92	87	83	78	73	69	64
162	108	103	99	94	89	85	80	75	71	66
163	110	105	100	96	91	86	82	77	72	68
164	112	107	102	98	93	88	84	79	74	70
165	113	109	104	99	95	90	85	81	76	71
166	115	111	106	101	97	92	87	83	78	73
167	117	113	108	103	98	94	89	84	80	75
168	119	114	110	105	100	96	91	86	82	77
169	121	116	112	107	102	98	93	88	83	79
170	123	118	113	109	104	99	95	90	85	81
171	125	120	115	111	106	101	97	92	87	83
172	126	122	117	112	108	103	98	94	89	84
173	128	124	119	114	110	105	100	96	91	86
174	130	125	121	116	111	107	102	97	93	88
175	132	127	123	118	113	109	104	99	95	90
176	134	129	124	120	115	110	106	101	96	92
177	136	131	126	122	117	112	108	103	98	94
178	138	133	128	124	119	114	109	105	100	95
179	139	135	130	125	121	116	111	107	102	97
180	141	137	132	127	123	118	113	108	104	99
181	143	138	134	129	124	120	115	110	106	101
182	145	140	136	131	126	122	117	112	108	103
183	147	142	137	133	128	123	119	114	109	105
184	149	144	139	135	130	125	121	116	111	107
185	150	146	141	136	132	127	122	118	113	108
186	152	148	143	138	134	129	124	120	115	110
187	154	150	145	140	135	131	126	121	117	112
188	156	151	147	142	137	133	128	123	119	114
189	158	153	149	144	139	134	130	125	120	116
190	160	155	150	146	141	136	132	127	122	118
191	162	157	152	148	143	138	134	129	124	119
192	163	159	154	149	145	140	135	131	126	121
193	165	161	156	151	147	142	137	133	128	123
194	167	162	158	153	148	144	139	134	130	125
195	169	164	160	155	150	146	141	136	132	127
196	171	166	161	157	152	147	143	138	133	129
197	173	168	163	159	154	149	145	140	135	131
198	175	170	165	160	156	151	146	142	137	132
199	176	172	167	162	158	153	148	144	139	134
200	178	174	169	164	160	155	150	145	141	136

TABLE IV.—*Factor for stature and age in women.*—Continued.

	51	52	53	54	55	56	57	58	59	60
151	41	36	31	27	22	17	13	8	3	−1.2
152	43	38	33	29	24	19	15	10	5	0.6
153	45	40	35	31	26	21	16	12	7	2
154	46	42	37	32	28	23	18	14	9	4
155	48	44	39	34	30	25	20	16	11	6
156	50	45	41	36	31	27	22	17	13	8
157	52	47	43	38	33	29	24	19	15	10
158	54	49	44	40	35	30	26	21	16	12
159	56	51	46	42	37	32	28	23	18	14
160	57	53	48	43	39	34	29	25	20	15
161	59	55	50	45	41	36	31	27	22	17
162	61	57	52	47	42	38	33	28	24	19
163	63	58	54	49	44	40	35	30	26	21
164	65	60	56	51	46	42	37	32	27	23
165	67	62	57	53	48	43	39	34	29	25
166	69	64	59	55	50	45	41	36	31	26
167	70	66	61	56	52	47	42	38	33	28
168	72	68	63	58	54	49	44	40	35	30
169	74	69	65	60	55	51	46	41	37	32
170	76	71	67	62	57	53	48	43	39	34
171	78	73	68	64	59	54	50	45	40	36
172	80	75	70	66	61	56	52	47	42	38
173	82	77	72	67	63	58	53	49	44	39
174	83	79	74	69	65	60	55	51	46	41
175	85	81	76	71	67	62	57	52	48	43
176	87	82	78	73	68	64	59	54	50	45
177	89	84	80	75	70	66	61	56	52	47
178	91	86	81	77	72	67	63	58	53	49
179	93	88	83	79	74	69	65	60	55	51
180	94	90	85	80	76	71	66	62	57	52
181	96	92	87	82	78	73	68	64	59	54
182	98	93	89	84	79	75	70	65	61	56
183	100	95	91	86	81	77	72	67	63	58
184	102	97	93	88	83	78	74	69	64	60
185	104	99	94	90	85	80	76	71	66	62
186	106	101	96	92	87	82	78	73	68	63
187	107	103	98	93	89	84	79	75	70	65
188	109	105	100	95	91	86	81	77	72	67
189	111	106	102	97	92	88	83	78	74	69
190	113	108	104	99	94	90	85	80	76	71
191	115	110	105	101	96	91	87	82	77	73
192	117	112	107	103	98	93	89	84	79	75
193	119	114	109	104	100	95	90	86	81	76
194	120	116	111	106	102	97	92	88	83	78
195	122	118	113	108	104	99	94	89	85	80
196	124	119	115	110	105	101	96	91	87	82
197	126	121	117	112	107	103	98	93	89	84
198	128	123	118	114	109	104	100	95	90	86
199	130	125	120	116	111	106	102	97	92	88
200	131	127	122	117	113	108	103	99	94	89

TABLE IV.—*Factor for stature and age in women.*—Concluded.

	61	62	63	64	65	66	67	68	69	70
151	−6	−11	−15	−20	−25	−29	−34	−39	−43	−48
152	−4	− 9	−13	−18	−23	−27	−32	−37	−41	−46
153	−2	− 7	−12	−16	−21	−26	−30	−35	−40	−44
154	−0	− 5	−10	−14	−19	−24	−28	−33	−38	−42
155	1	− 3	− 8	−13	−17	−22	−27	−31	−36	−41
156	3	− 1	− 6	−11	−15	−20	−25	−29	−34	−39
157	5	1	− 4	− 9	−14	−18	−23	−28	−32	−37
158	7	2	− 2	− 7	−12	−16	−21	−26	−30	−35
159	9	4	− 0	− 5	−10	−15	−19	−24	−29	−33
160	11	6	1	− 3	− 8	−13	−17	−22	−27	−31
161	13	8	3	− 1	− 6	−11	−15	−20	−25	−30
162	14	10	5	0	− 4	− 9	−14	−18	−23	−28
163	16	12	7	2	− 2	− 7	−12	−16	−21	−26
164	18	13	9	4	− 1	− 5	−10	−15	−19	−24
165	20	15	11	6	1	− 3	− 8	−13	−17	−22
166	22	17	12	8	3	− 2	− 6	−11	−16	−20
167	24	19	14	10	5	0	− 4	− 9	−14	−18
168	26	21	16	11	7	2	− 3	− 7	−12	−17
169	27	23	18	13	9	4	− 1	− 5	−10	−15
170	29	25	20	15	11	6	1	− 4	− 8	−13
171	31	26	22	17	12	8	3	− 2	− 6	−11
172	33	28	24	19	14	10	5	0	− 4	− 9
173	35	30	25	21	16	11	7	2	− 3	− 7
174	37	32	27	23	18	13	9	4	− 1	− 5
175	38	34	29	24	20	15	10	6	1	− 4
176	40	36	31	26	22	17	12	8	3	− 2
177	42	37	33	28	23	19	14	9	5	0
178	44	39	35	30	25	21	16	11	7	2
179	46	41	37	32	27	22	18	13	8	4
180	48	43	38	34	29	24	20	15	10	6
181	50	45	40	36	31	26	22	17	12	8
182	51	47	42	37	33	28	23	19	14	9
183	53	49	44	39	35	30	25	21	16	11
184	55	50	46	41	36	32	27	22	18	13
185	57	52	48	43	38	34	29	24	20	15
186	59	54	49	45	40	35	31	26	21	17
187	61	56	51	47	42	37	33	28	23	19
188	63	58	53	48	44	39	34	30	25	20
189	64	60	55	50	46	41	36	32	27	22
190	66	62	57	52	48	43	38	33	29	24
191	68	63	59	54	49	45	40	35	31	26
192	70	65	61	56	51	47	42	37	33	28
193	72	67	62	58	53	48	44	39	34	30
194	74	69	64	60	55	50	46	41	36	32
195	75	71	66	61	57	52	47	43	38	33
196	77	73	68	63	59	54	49	45	40	35
197	79	74	70	65	60	56	51	46	42	37
198	81	76	72	67	62	58	53	48	44	39
199	83	78	74	69	64	59	55	50	45	41
200	85	80	75	71	66	61	57	52	47	43